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RADIOGRAPHY. VOLUME I - ORIGIN AND NATURE OF RADIATION

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Radiography. Vol. I Origin + Nature of Radiation

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PREFACE

~~Programmed Instruction Handbook~~ Radiography ~~Testing (5330.14)~~) is home study material for familiarization and orientation on Nondestructive Testing. This material was planned and prepared for use with formal Nondestructive Testing courses. Although these courses are not scheduled at this time the material will be a valuable aid for familiarization with the basics of Nondestructive Testing. When used as prerequisite material, it will help standardize the level of knowledge and reduce classroom lecture time to a minimum. The handbook has been prepared in a self-study format including self-examination questions.

It is intended ~~that handbook 5330.9~~, Introduction to Nondestructive Testing, be completed prior to reading other ~~Programmed Instruction Handbooks of the Nondestructive Testing~~ series. The material presented in these documents will provide much of the knowledge required to enable each person to perform his Nondestructive Testing job effectively. However, to master this knowledge considerable personal effort is required.

This Nondestructive Testing material is part of a large program to create an awareness of the high reliability requirements of the expanding space program. Highly complex hardware for operational research and development missions in the hazardous and, as yet, largely unknown environment of space makes it mandatory that quality and reliability be developed to levels heretofore unknown. The failure of a single article or component on a single mission may involve the loss of equipment valued at many millions of dollars, not to mention possible loss of lives, and the loss of valuable time in our space timetable.

A major share of the responsibility for assuring such high levels of reliability, lies with NASA, other Government agencies, and contractor nondestructive Testing personnel. These are the people who conduct or monitor the tests that ultimately confirm or reject each piece of hardware before it is committed to its mission. There is no room for error -- no chance for reexamination. The decision must be right -- unquestionably -- the first time. This handbook is one step toward that goal.

General technical questions concerning this publication should be referred to the George C. Marshall ~~Space Flight~~ Center, Quality and Reliability Assurance Laboratory, Huntsville, Alabama 35812.

The recipient of this handbook is encouraged to submit recommendations for updating and comments for correction of errors in this initial compilation and gen'l technical questions to George C. Marshall Space Flight Center, Quality and Reliability Assurance Laboratory (R-QUAL-OT), Huntsville, Alabama 35812.

ACKNOWLEDGMENTS

This handbook was prepared by the Convair Division of General Dynamics Corporation under NASA Contract NAS8-20185. Assistance in the form of process data, technical reviews, and technical advice was provided by a great many companies and individuals. The following listing is an attempt to acknowledge this assistance and to express our gratitude for the high degree of interest exhibited by the firms, their representatives, and other individuals who, in many cases, gave considerable time and effort to the project.

Aerojet-General Corp.; Agfa-Geveart Co. of America, Inc.; Aircraft X-Ray Co.; Automation Industries, Inc., Sperry Products Division; Avco Corporation; Babcock & Wilcox Co.; Balto Electric Corp.; The Boeing Company; The Budd Co., Instruments Division; Douglas Aircraft Co., Inc.; E. I. DuPont De Nemours & Co., Inc.; Eastman Kodak Company, Radiography Markets Division; General Analine & Film Corp.; Grumman Aircraft; Lockheed Aircraft Corp.; The Martin Co. (Denver); McDonnell Aircraft Corp.; C. H. F. Muller Gmbh, Rontgenwerk; North American Aviation, Inc.; Phillips Electronic Instruments; Picker X-Ray Corp.; Professor Harry Richardson, L.S.U.; Rohr Corporation; Richard Seifert & Co. Rontgenwerk; Southern California Cancer Center; Southwest Research Institute; St. Louis Testing Laboratories, Inc.; Technical Operations, Inc.; Uresco, Inc.; X-Ray Products Corp.

Our thanks is also extended to the many individuals who assisted in the testing of the materials to validate the teaching effectiveness. Their patience and comments contributed greatly to the successful completion of the handbook.

INTRODUCTION

Wilhelm Roentgen really started something when he stumbled onto his mysterious "X" rays back in 1895. His discovery was one of the first of a seemingly unending stream of scientific advances in the years that have followed.

There is no doubt that Roentgen's scientific contemporaries were startled by his discovery, but can you imagine the reaction of the nonscientific population when they learned of the new ray that could "see through solid objects? (Remember, their's was a horse and buggy society - they weren't conditioned to the rapid-fire scientific announcements that we hear almost daily.) It has even been reported that the shy victorian ladies of the period started bathing with their clothes on because they suspected "those wicked scientists" of watching through the walls.

Today we have a more realistic knowledge of X-rays. We all know that they are not playthings and can cause physical damage if used improperly. We also know that they have wide medical application. Many of you have some degree of knowledge of X-ray use for the inspection of manufactured parts. Regardless of your present level of knowledge, this series of programmed instruction books is intended to give you a sound basis of theoretical and practical knowledge on which to continue your training as radiographers.

<u>THE RADIOGRAPHIC INSPECTION PROGRAMMED INSTRUCTION</u> series is carefully sequenced to teach the background material you will need before you set foot in a radiographic laboratory. The five volumes should be read in sequence since much of the material in later volumes is based on facts learned in the first volumes. In addition, successful completion of the radiographic testing series is dependent on prior completion of ~~5330.9~~ INTRODUCTION TO NONDESTRUCTIVE TESTING. So, if you haven't already done so, read ~~5330.9~~ before you start this radiographic testing program.

Here is a brief account of the contents of each volume of the Radiographic Testing Programmed Instruction series:

Volume I — ORIGIN AND NATURE OF RADIATION

To properly understand the radiographic processes, it is necessary to have a knowledge of the origin and nature of X-radiation and gamma radiation. Volume I is devoted to teaching the fundamentals of atomic theory; the characteristics of X-rays, gamma rays, and certain other particulate radiations; and the interactions of these radiations with matter. The presentation is admittedly limited and, in several cases, broadly generalized. The intent of Volume I is to present only those facts necessary to a proper understanding of the material contained in subsequent volumes of the series.

Volume II — RADIATION SAFETY

Since safety is an important aspect of radiographic testing, the total contents of Volume II are devoted to that subject. Radiation presents a hazard to those who work around it. However, if the proper safety precautions are used and all the safety rules followed, radiography need not be a hazardous job. This volume will introduce you to radiation measurement techniques and devices; the means by which radiation doses are limited for workers; radiation doses and their effects; personnel protection; and some of the procedures and regulations which you will encounter in on-the-job situations.

Volume III — RADIOGRAPHIC EQUIPMENT

The purpose of Volume III is to present to the reader a solid, full range coverage of radiographic equipment. In the five chapters of this volume you will find: an elaboration of the basic theory pertaining to the generation of X-radiation; a discussion which includes the X-ray generation equipment, e.g., the X-ray tube and its components, tube cooling, focal spot, etc.; power equipment, circuits, rectification, and special electron accelerators; gamma ray source equipment and ratings; and other related radiographic equipment. It is intended that upon completion of this volume, the reader will be well grounded in knowledge of radiographic equipment and how it functions.

Volume IV — MAKING A RADIOGRAPH

Volume IV discusses those theories and practices directly related to the production of a radiograph. The inter-relationship between radiation, specimen, and film is reviewed. The factors that affect the quality of the radiograph are identified and their effects on the final radiograph are described. This volume teaches the mathematical processes that are necessary in computing exposures and teaches the use of special charts commonly used in radiography. The procedures to be followed in selecting the required equipment and techniques are described. And finally, several specialized techniques are taught.

Volume V — FILM HANDLING AND PROCESSING

The well rounded radiographer should have a knowledge of radiographic film - its handling and processing. Volume V introduces you to the elements of a typical darkroom, the care of film, the step-by-step process of developing and fixing a radiograph, and some of the consequences of improper handling or processing. Limited coverage is also given automatic film processors.

INSTRUCTIONS

The pages in this book should not be read consecutively as in a conventional book. You will be guided through the book as you read. For example, after reading page 3-12, you may find an instruction similar to one of the following at the bottom of the page —

- Turn to the next page
- Turn to page 3-15
- Return to page 3-10

On many pages you will be faced with a choice. For instance, you may find a statement or question at the bottom of the page together with two or more possible answers. Each answer will indicate a page number. You should choose the answer you think is correct and turn to the indicated page. That page will contain further instructions.

As you progress through the book, ignore the back of each page. THEY ARE PRINTED UPSIDE DOWN. You will be instructed when to turn the book around and read the upside-down printed pages.

As you will soon see, it's very simple — just follow instructions.

TURN TO THE NEXT PAGE

CHAPTER 1 – STRUCTURE OF THE ATOM

In order to understand the subject of radiography, you must first understand something about the nature of matter - its structure and characteristics. In this chapter you are going to explore the atom in a very general way. You will look at some of the particles that make up the atom and study their arrangement within the atom. You will also learn to identify atoms by a system that considers the type and number of particles in various atoms.

Consider first the very basic particles from which all matter is composed, the PROTON, the NEUTRON, and the ELECTRON. There are others in addition to these, but they are of no particular importance to us in this discussion. The PROTON, NEUTRON, and ELECTRON form the framework for all matter; the other particles are difficult to detect and some have a very fleeting existence. They are the "fuzz" that exists alongside our three basic particles.

Let's take a look at these three basic particles or units (the symbols shown are those we will use in later discussions):

PROTON ⊕ — This is a relatively heavy particle with a single positive (+) electrical charge. Fix the name and charge in your mind. "Pro" means "for" or "with" - a positive direction.

NEUTRON ○ — This particle is very close to the same size and weight as the proton, however it is neutral - it has no electrical charge as the name indicates.

ELECTRON ⊖ — This is a very light particle compared to the proton or neutron - about 1/1840th of their weight. It has a single negative (-) electrical charge.

PLEASE TURN TO THE NEXT PAGE.

From page 1-1

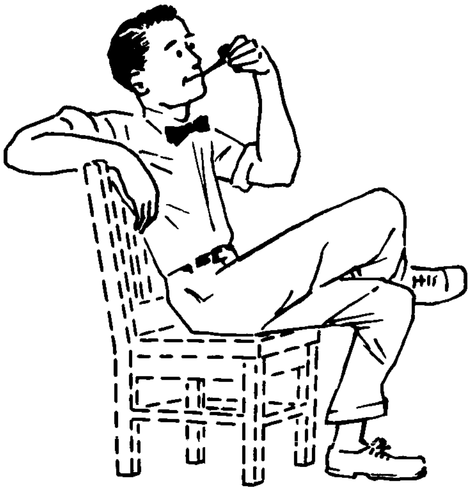
PROTONS & NEUTRONS & ELECTRONS COMBINE TO FORM ATOMS.
⊕ O ⊖

The number of each of these particles that make up the atom, determines the kind of atom it is.

There are over 100 different kinds of basic atoms known and the number is increasing as scientists create new ones. Each of these basic atoms is identified as an ELEMENT and is given a name. Oxygen, iron, sulfur, and lead are some common examples of basic elements.

Elements, or chemical combinations of elements (molecules), form all the things we see in our everyday living. The chair you are sitting on, the ceiling overhead, the air around you, are all made up of atoms or combinations of different atoms or elements.

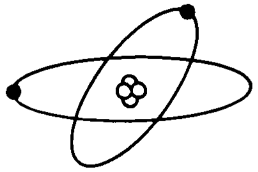
Atoms are extremely small pieces of matter. There are billions of carbon atoms in the tip of a pencil! This is an astounding fact when you first hear it, but perhaps more astounding is the fact that over 99.99% of an atom is empty space! At this moment you are sitting on less than 1/100th of one percent of what you think you are.



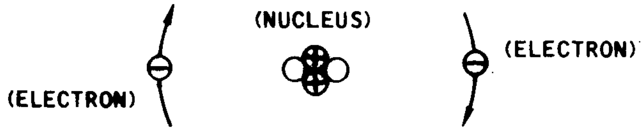
Please turn to page 1-3

Let's take a look at an atom of the element helium, a very light gas.

This is the way the atom probably looks.



We'll examine it by showing it this way.



Notice that the protons and neutrons are packed together in the center of the atom. This group of protons and neutrons is called the NUCLEUS of the atom.

In the helium atom shown above, there are 2 protons and 2 neutrons in the nucleus. The neutrons are neutral - they have no electrical charge, but each of the 2 protons has a single positive electrical charge, therefore the nucleus of the helium atom has a plus 2 electrical charge.

In order for it to be complete, the helium atom must be electrically neutral, therefore, 2 electrons, each with a single negative charge, orbit or circle around the nucleus.

Considering the size of the nucleus and the electrons, the distance at which the electrons orbit is very large and all the space between the nucleus and the electrons is empty. This is the reason for the statement on the last page about 99.99+ percent of the atom being empty.

Read the following statements, pick the one that you think is correct and turn to the indicated page.

All atoms have 2 protons and 2 neutrons in the nucleus - - - - - - - - - page 1-4

All complete atoms must have an equal number of protons and electrons - page 1-5

You picked, "All atoms have 2 protons and 2 neutrons in the nucleus."

The helium atom shown on page 1-3 was picked as a simple example of an atom. It is not typical of all atoms. The helium atom does have 2 protons and 2 neutrons in its nucleus, but it is the only atom that does. Atoms of other elements have different numbers of protons and neutrons in their nuclei. We will discuss this some more later in the program.

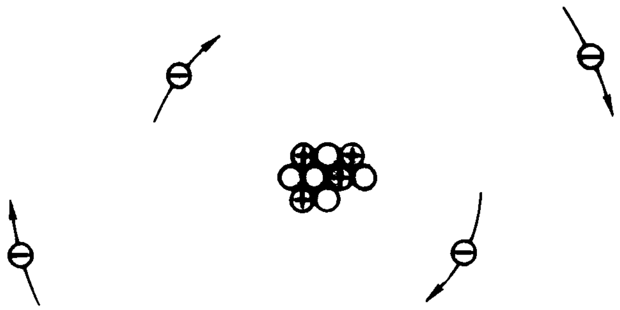
The point we are trying to make at this time is that a complete atom must be electrically neutral, therefore, all complete atoms must have an equal number of protons (+ charges) and electrons (- charges).

Now turn back to page 1-3, reread the material, and make another selection.

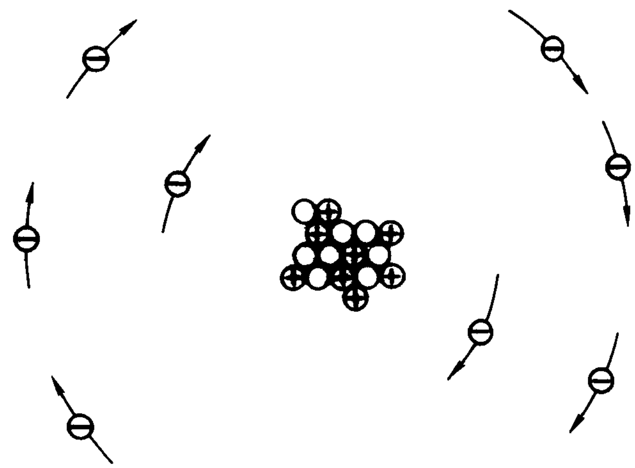
From page 1-3

Very good! All complete atoms must have an equal number of protons and electrons. You understand the point we are trying to make, that all complete atoms must be electrically neutral.

Here are some more examples of complete (electrically neutral) atoms:



This is an atom of <u>beryllium.</u>
Count the number of protons (⊕),
Neutrons (○), and electrons (⊖).



This is an atom of <u>oxygen.</u>
Count the number of protons,
neutrons, and electrons.

From an examination of these atoms, what fact becomes apparent?

Although the number of electrons must equal the number of protons, the number of neutrons in an atom may be quite different - - - - - - - page 1-6

The number of neutrons in an atom must be the same as the number of protons and electrons - - - - - - - - - - - - - - - - - - page 1-8

You say that the number of neutrons in an atom can be different than the number of protons or electrons.

You are absolutely right. And this brings up our next point.

The number of protons (⊕) in an atom (and therefore the number of electrons (⊖) since they are equal) determines the kind of atom, or element. For example, all atoms that have 8 protons are atoms of oxygen; and all atoms that have 26 protons are atoms of iron.

Let's take a look at a partial listing of the basic elements, starting with the simplest, and see how they relate to the number of protons in the nucleus:

all atoms that contain 1 proton are hydrogen atoms
all atoms that contain 2 protons are helium atoms
all atoms that contain 3 protons are lithium atoms
all atoms that contain 4 protons are beryllium atoms
↓
all atoms that contain 26 protons are iron atoms
all atoms that contain 27 protons are cobalt atoms
all atoms that contain 28 protons are nickel atoms
↓
all atoms that contain 77 protons are iridium atoms
all atoms that contain 78 protons are platinum atoms
etc - etc etc

The above list could be filled in and extended, one additional proton at a time, to more than 100. And every number would identify a different basic element.

Turn to page 1-7.

The basic elements, such as those listed on the last page, can be identified or labeled in several ways.

The obvious way is to use a name, just what we have been doing so far. For example, hydrogen, helium, cobalt, iridium, etc.

In addition, each of the elements has a symbol or abbreviation that is very often used instead of the full name. For example,

H IS HYDROGEN	Co IS COBALT
He IS HELIUM	Ir IS IRIDIUM

Sometimes the symbols don't look much like the name, for example, gold. Its symbol is Au.

There is a third way of identifying a basic element that should be evident to you. Since each basic element has a specific number of protons in each of its atoms, any element can be identified by this number.

The number of protons (⊕) in the nucleus of an atom is called the ATOMIC NUMBER or Z NUMBER. No two elements have the same ATOMIC (Z) number, because no two elements have the same number of protons in their atoms. Look at our typical elements again.

HYDROGEN (H) HAS Z OF 1	COBALT (Co) HAS Z OF 27
HELIUM (He) HAS Z OF 2	IRIDIUM (Ir) HAS Z OF 77

An atom that has 77 protons, 115 neutrons and 77 electrons has an ATOMIC (Z) number of -

115 - page 1-9

77 - page 1-10

From page 1-5

Sorry, but you made a bad choice. The number of neutrons in an atom is not necessarily the same as the number of protons or electrons.

If you counted the number of particles in the beryllium atom you found 4 protons and 5 neutrons!

Although many atoms have an equal number of protons and neutrons (such as the oxygen atom on page 1-5), it is not a rule. In fact, most atoms have an unequal number.

Remember, the number of protons (+ charges) and electrons (- charges) must be equal in a complete atom, however, the number of neutrons (neutral particles) may be different.

Please turn to page 1-6.

Not so. An atom that has 77 protons, 115 neutrons, and 77 electrons does not have an atomic (Z) number of 115.

The atomic (Z) number represents the number of protons in the atom, not the number of neutrons. An atom with a Z number of 115 would have 115 protons in its nucleus and 115 electrons in orbit to balance the electrical charge. Such an atom is not known to exist at the present time.

Don't confuse proton ($\oplus$) with neutron ($\bigcirc$).

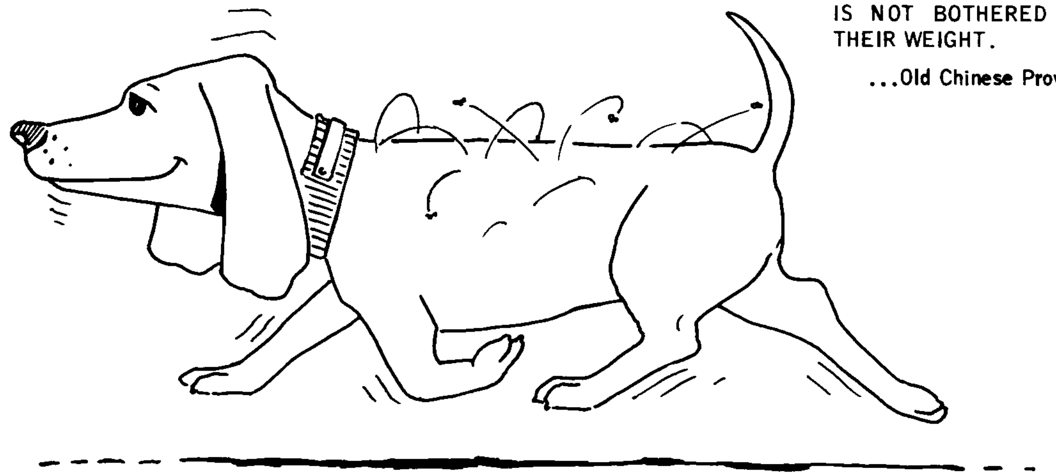
Please return to page 1-7, reread the material and make another selection.

Yes. You have the right idea. An atom with 77 protons would have a Z number of 77. The number of neutrons has nothing to do with the atomic (Z) number.

As a matter of interest, the atom described - 77 protons, 115 neutrons, and 77 electrons - is radioactive iridium, a source of radiation commonly used in radiography.

Let's go on. We mentioned earlier that protons and neutrons are about equal in size and weight. The only difference, so far as we are concerned, is that the proton has a positive charge and the neutron has no charge. We also said that the electron is very much lighter than the proton or neutron, in fact only 1/1840th as heavy.

If we could weigh a single atom, most of the reading on the scale would be caused by the nucleons (protons and neutrons). The electrons and other incidental particles (fuzz) are so light that they would not make any significant contribution to the weight.



HE WHO CARRIES FLEAS IS NOT BOTHERED BY THEIR WEIGHT.

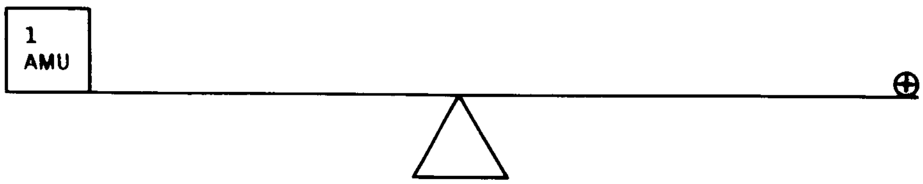
...Old Chinese Proverb

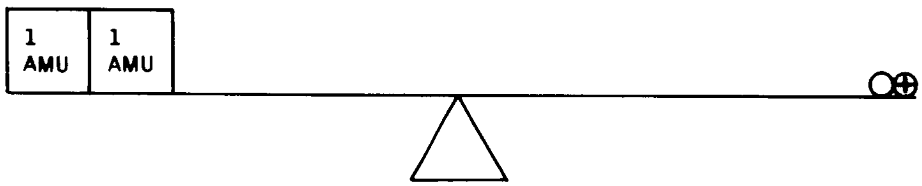
Please turn to the next page.

Because atoms are such extremely small bits of matter, it wouldn't make sense to try to express their weight in ounces or grams. Instead, a smaller unit of weight is used - The "atomic mass unit" or "AMU".

Technically, one AMU is 1/12 of the weight or mass of a carbon atom that has 6 protons and 6 neutrons in its nucleus.

<u>Practically, however, one AMU is almost exactly equal to the weight or mass of one proton or one neutron.</u>





Now let's take an atom of the radioactive iridium that we mentioned before. The atom is made up of 77 protons, 115 neutrons, and 77 electrons. If it were possible to place this atom on a sensitive scale, what would be its approximate weight in AMU's?

269 AMU's - page 1-12

192 AMU's - page 1-13

Nope. You picked the wrong answer.

One AMU is almost exactly equal to the weight or mass of one proton or one neutron.

However, an electron weighs only 1/1840th as much as a proton or neutron.

You made the mistake of adding the electrons to the weight figure. The 77 electrons in the atom would only add a minor fraction of one AMU to the total weight, therefore, the weight of the atom would be

77 (protons) + 115 (neutrons) = 192 AMU's + a very small fraction

The weight of the iridium atom is approximately 192 AMU's.

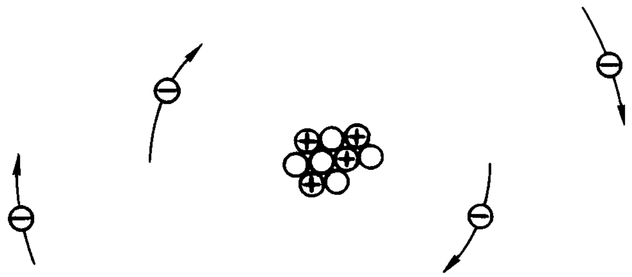
Turn to page 1-13.

Correct. The approximate weight of the iridium atom is 192 AMU's. The electrons, being so light, do not add much to the weight of the protons and neutrons.

As we shall find out in the next chapter, all atoms of the same element do not weigh the same because there can be variations in the number of neutrons in different atoms of the same element. Therefore we must have a means of identifying atoms, not only by Z number (which represents the number of protons only), but also by some method that takes into account the varying number of neutrons. This is done by assigning to each type of atom a number that is equal to the total number of protons and neutrons in the nucleus.

Since this number is also the approximate weight or mass of the atom in AMU's, the number is known as the MASS NUMBER or "A" NUMBER.

For example, here is the beryllium atom that we looked at a few pages back -



The atom has a Z number of 4 because it has only 4 protons. However, the A number (mass) for this particular atom of beryllium is 9, the total number of protons and neutrons.

The A number represents the total number of protons and neutrons in any atom.

Turn to page 1-14.

[redacted]

Don't be too concerned about AMU's (atomic mass units). In your work as a radiographer you may see the term occasionally, but it is of little importance except at the engineering levels. We used it here merely to assist in the definition of the MASS or A number.

The use of the letters Z and A to represent atomic number and mass number, respectively, is unfortunate because it is sometimes confusing. It may help to differentiate between the two if you remember that "A" does not stand for "atomic" number - it means "mass". You have to go to the opposite end of the alphabet to find the designation for "atomic" number.

Here are the definitions again:

Z = atomic number. The number of protons only in the nucleus. This number determines the type of element.

A = mass number. The number of protons and neutrons in the nucleus. This number identifies different atoms of the same element.

Turn to page 1-15.

From page 1-14

Let's summarize the facts we've learned in this section concerning basic atomic particles and atoms.

First, atoms are composed of three basic particles - protons, neutrons, and electrons. There are others, but they are not important to us.

Second, a proton has a single positive electrical charge, a neutron has no electrical charge, and an electron has a single negative electrical charge.

Third, the protons and neutrons are grouped together in the center of the atom and are called the nucleus. The electrons orbit at some distance from the nucleus.

Fourth, a complete atom must be electrically neutral. The number of electrons must equal the number of protons.

Fifth, all atoms of one element have the same number of protons. When the number of protons changes, it is a different element.

Sixth, the number of protons is called the "atomic" number or "Z" number.

Seventh, the total number of protons and neutrons is called the "mass" number or "A" number.

In the next chapter we will find out what happens when the number of neutrons in an atom changes but the number of protons remains the same. (Same Z number but different A number.)

Turn to page 1-16 for a review of Chapter 1.

From Page 1-15

1. The next few pages are different from the ones which you have been reading. There are ___________ arrows on this entire page. (Write in the correct number of arrows.) Do not read the frames below. FOLLOW THE ARROW and turn to the TOP of the next page. There you will find the correct word for the blank line above.

5. positive (plus)

6. Of the three basic atomic particles, the one that has no electrical charge is the ___________________.

10. electrons, protons

11. Although the number of electrons and protons in an atom must be the same, the number of ______________ may be different.

15. protons, neutrons

16. Every atom can be identified, not only by its atomic number (Z number), but by a mass number, or "A" number, that represents the total number of ______________ and ______________ in the atom's _________________.

This is the answer to the blank in Frame number 1.

1. four

Frame 2 is next

2. These sections will provide a review of the material you have covered to this point. There will be one or more blanks in each f____________.

Turn to the next page.
Follow the arrow.

6. neutron

7. An electron (⊖) has a single ______________ electrical charge.

11. neutrons

12. Each of the basic elements is characterized by the number of ______________ in its nucleus.

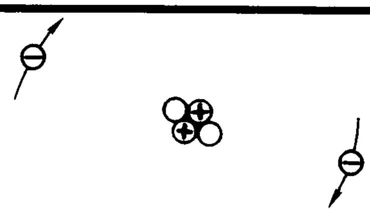
16. protons, neutrons, nucleus

17. A given element always has the same ________________ number.

2. frame

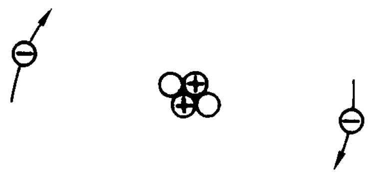
3. By following the arrows or instructions you will be directed to the section which follows in sequence. Each section presents information and requires the filling in of ________.

7. negative (minus)



8. In an atom, the protons and neutrons are grouped together in the center of the atom. This grouping is called the ________ of the atom.

12. protons

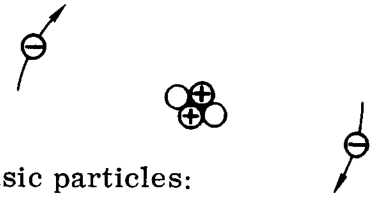


13. If an atom of helium could be examined, you would find 2 protons in its nucleus. All atoms that contain only 2 protons in the nucleus are atoms of ________.

17. atomic (Z)

18. Atoms of the same element always have the same atomic (Z) number, but they may have different ________ numbers because the number of ________ in the nuclei may vary.

3. blanks (or spaces or words)



4. Now for the review: Atoms are made up of three basic particles: ______________ (⊕), ______________ (○), and ______________ (⊖).

8. nucleus

9. An atom consists mostly of empty space because the ______________ orbit at a relatively large distance from the nucleus.

13. helium

14. Each element is identified by a name, symbol, or atomic number. The atomic number, or z number as it is sometimes called, is actually a count of the number of ______________ in the ______________ of an atom of the element.

18. mass (A), neutrons

19. The atomic (Z) number represents the number of ______________ in the nucleus. The mass (A) number represents the number of ______________ and ______________ in the nucleus.

4. protons, neutrons, electrons

5. A proton (⊕) has a single ________________ electrical charge.

Return to page 1-16, frame 6.

9. electrons

10. In any complete atom, the number of ________________ must equal the number of ________________.

Return to page 1-16, frame 11.

14. protons, nucleus

15. Most of the weight of an atom is caused by the heavy particles: ________________ and ________________.

Return to page 1-16, frame 16.

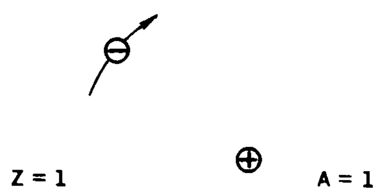
19. protons, protons, neutrons

20. Now turn to the next page and continue with Chapter 2.

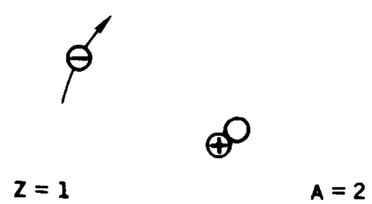
CHAPTER 2 — RADIOACTIVE MATERIALS

In the last chapter you learned that an element is identified by the number of protons in its nucleus, or in other words, its Z number. We also indicated that any one element may vary in the number of neutrons it has in its nucleus, that is, the same element may have several A numbers. In this chapter we will elaborate on this idea of different numbers of neutrons in atoms of the same element and consider the effect of this situation on the stability of the atoms. You will learn the primary processes through which radioactivity takes place and some methods of measuring radioactivity.

Let's take a look at some atoms of the same element in which the A numbers are different. We'll use the element hydrogen as an example - it is the simplest and lightest of all the elements. Hydrogen has a Z number of 1 so we know that all atoms of hydrogen will have 1 proton in its nucleus.

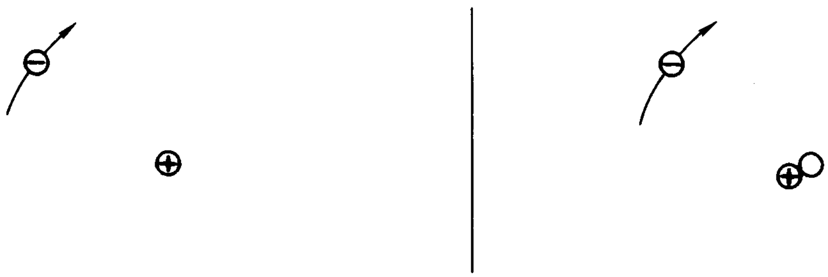


This is the common form of hydrogen. It has 1 proton and 1 balancing electron. It has no neutrons. (This is the only atom that has no neutrons in its nucleus.)



This is a less common form of hydrogen. We know it is hydrogen because it has 1 proton. But this atom of hydrogen also has 1 neutron in its nucleus. It is sometimes known as "heavy" hydrogen, because it weighs twice as much as common hydrogen.

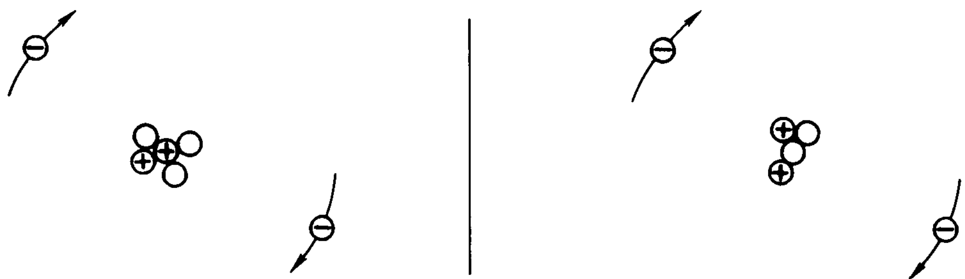
Turn to the next page



These two forms or types of hydrogen are called "isotopes" of hydrogen. (icé-o-tope) Isotopes of an element might be compared with breeds of dogs or cats. Just as there are poodles, spaniels, and other breeds of dogs, there are isotopes or breeds of an element. The whole family of atoms that belong to any one element are called isotopes of that element.

It would be a little awkward to try to describe some specific isotope by saying, "the hydrogen atom that has a mass number of 2", so we simply refer to it as "hydrogen two" or "H-2" when writing it. The two isotopes of hydrogen shown above are H-1 and H-2.

Let's look at some other atoms -



Pick the statement below that you think is correct.

The two atoms shown are isotopes of the same element - - - - - - - - - - - - page 2-3

The two atoms shown are not isotopes of the same element - - - - - - - - - - page 2-4

Yes. The two atoms shown are isotopes of the same element.

The atoms are isotopes of the element helium (symbol He). They both have the same atomic (Z) number, or, in other words, the same number of protons. They are different isotopes because they have different mass (A) numbers, or, in other words, different total numbers of protons and neutrons. They should be referred to as He-5 and He-4.

Many isotopes of the various elements occur in nature; however, in recent years a great many new ones have been created artificially in nuclear reactors and particle accelerators (atom smashers).

These artifical isotopes are created by bombarding an element with swarms of neutrons. Since large numbers of free neutrons are given off by the atomic fission process, a nuclear reactor is an ideal place to make new isotopes. After being exposed for a time to the high concentration of neutrons in a nuclear reactor, the atoms of the basic element will absorb extra neutrons. The A number of these atoms has increased. The number of protons remains the same so the changed atom is still the same element, but it is a different type or isotope of the element.

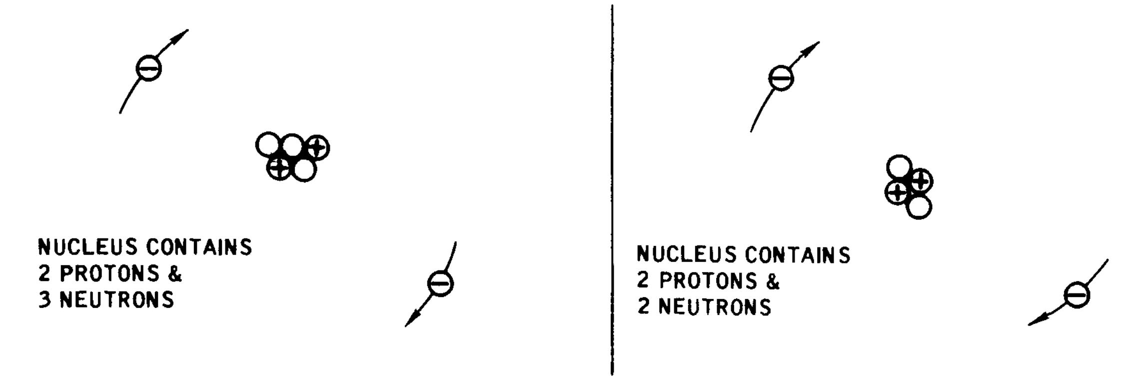
When a new isotope is content with its form, when the extra neutron does not upset the balance in the nucleus, the isotope is said to be "stable." It just stays the way it is.

What would you suspect about the atom of an isotope that did not like the new form, whose nucleus was thrown out of balance by the added neutron?

It might not like it, but it is very difficult to change an atom. It would continue in its new form - page 2-5

It would change itself to a form that is more comfortable - - - - - - - - - - - page 2-6

You say that the two atoms are not isotopes of the same element. Let's take another look -



Remember that atoms with the same atomic (Z) number are the same element. The two atoms shown are the same element because they both have 2 protons, therefore the same Z number.

However —

Their "A" numbers are different —

2 (protons) + 3 (neutrons) = 5

2 (protons) + 2 (neutrons) = 4

Therefore they are different forms or "isotopes" of the same element.

Remember - "Z" is the KEY to whether it is the same or a different element.

Turn to page 2-3

From page 2-3

You say that it is difficult to change an atom and the atom would continue in its new form.

We agree that ordinarily the binding forces in an atom would prevent any change to its structure except with extreme difficulty. However, this is a different situation. The atom itself is in a state of unrest and has to make some internal adjustment in order to become stable.

Turn to page 2-6 for a discussion of how this change takes place.

From page 2-3

That's right. It would change itself to a form that is more comfortable.

An unstable atom will disintegrate or decay into a more stable form. By disintegrate we don't mean that it falls apart - the atom throws off or emits tiny particles or bits of energy until it is again stable. Such atoms, the ones that are unstable, are said to be radioactive.

A number of radioactive isotopes (radioisotopes) are found in nature. You've all heard the stories about radium - how it was discovered and used years ago. It, together with uranium, are probably the better known natural radioactive isotopes. Radioisotopes in nature are rather scarce. If at one time there were more, they have disintegrated and become stable over the billions of years the earth has existed.

In recent years, since scientists have had access to nuclear reactors, whole families of new radioactive isotopes have been created. This process of creating artificial radioisotopes is called ACTIVATION. A stable isotope is activated in a nuclear reactor when free neutrons penetrate the nuclei and increase the A number. The resulting new isotope is unstable, or radioactive.

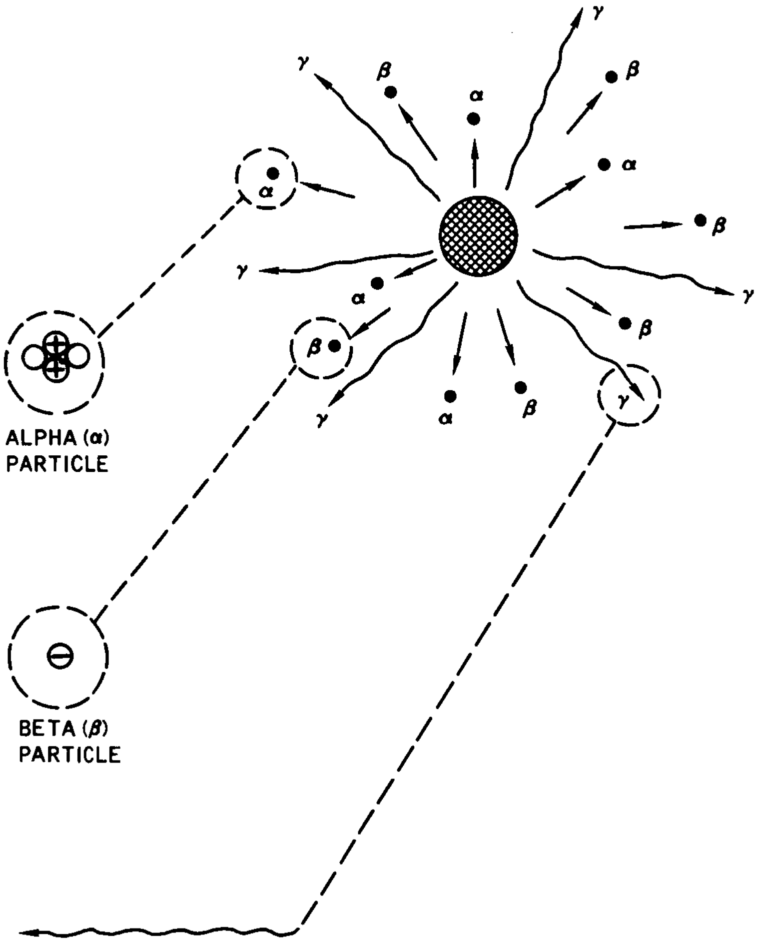
Some of these new artificial radioisotopes disintegrate so rapidly that they are difficult to detect. Others have longer lives and depending on their other characteristics are very useful in many scientific and industrial applications. Radiography is one use for certain radioisotopes.

Please turn to page 2-7

From page 2-6

You have learned that unstable isotopes will seek stability through a process of decay or disintegration - they are radioactive. During this decay process, tiny particles traveling at high speeds are emitted and/or energy in the form of waves is given off.

All of this radiation - particles and waves - comes from the nucleus of the radioactive atom.



This is a piece of radioactive material. Its atoms are decaying.

This is an "alpha" (α) particle. It is the biggest and heaviest of the radiation particles and is composed of 2 protons and 2 neutrons.

This is a "beta" (β) particle. It is a very light particle and is actually a high speed electron.

The wiggly line represents a "gamma" (γ) ray. A gamma ray is a wave form of energy, not a particle.

How does this radiation affect an atomic nucleus? Let's take an atom of the radioactive element polonium (Po-210). It has 84 protons and 126 neutrons in its nucleus and when it decays, it emits an alpha particle (2 protons & 2 neutrons). How would you describe the resulting atom in terms of A and Z numbers?

Z=84 and A=122 - Page 2-8

Z=82 and A=206 - Page 2-9

From page 2-7

You picked, "Z=84 and A=122"

You were apparently thinking that the atom that results from the decay process should be a new isotope of the original element, polonium, since you did not change the Z number.

Remember that an alpha particle consists of 2 protons and 2 neutrons. They come from the nucleus of the radioactive atom, therefore the Z number (number of protons) must change.

Also remember that the A number is not a count of the number of neutrons. It represents the mass of the atom or the total number of protons and neutrons.

Please turn back to page 2-7 and make a new choice.

From page 2-7

You have the right idea. A different element with a Z number of 82 has resulted from the radioactive decay of the atom. The atom of Po-210 has decayed into a stable isotope of lead, Pb-206. Notice that the A number of the lead is 4 less than the A number of the polonium as a result of 2 protons and 2 neutrons being emitted.

As shown above, alpha (α) particle decay will always result in a new element with two less protons and with an A number four less than the original.

When radioactive decay of an atom takes place by the emission of a beta (β) particle, the process is a little more complex. In order to understand beta (β) particle decay, we'll have to take a little closer look at the neutron. Consider the neutron as being a combination of a proton (⊕) and an electron (⊖).

⊕ AND ⊖ = ± (NEUTRON)

Notice that we have not changed the basic idea of a neutral particle. The neutron has a single positive charge and a single negative charge, therefore it is electrically neutral.

This concept of a neutron is necessary to our discussion because we are going to start changing neutrons (○) into protons (⊕) by subtracting electrons (⊖). Don't get the idea that this is a common occurrence in atoms. In a stable atom, the protons, neutrons, and electrons are perfectly content to stay the way they are. Only in an unstable, or radioactive, atom will you find forces that will change one particle into another.

Turn to the next page

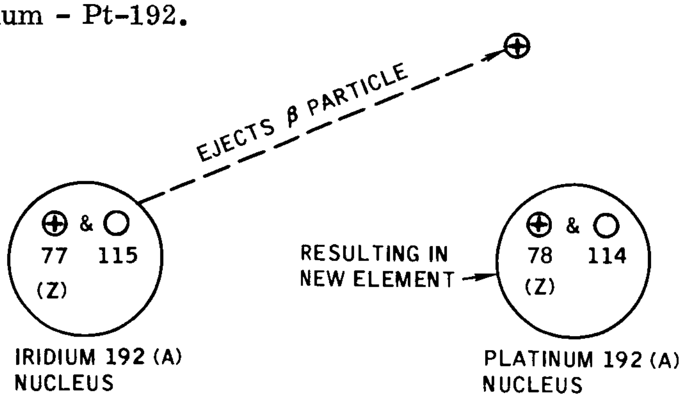
Some radioactive nuclei emit beta (β) particles (high speed electrons) when they decay. Note that these are not orbital electrons - they originate in the nucleus. Normally, we don't think of a nucleus as having any electrons in it; however, as discussed on the last page, a neutron is a combination of a proton (⊕) and an electron (⊖).

When the electron is removed, the neutron becomes a proton.

This is what happens during beta (β) decay. A neutron in the radioactive nucleus gives off a beta particle (nuclear electron) and becomes a proton.

As an example, consider the radioactive isotope of iridium, Ir-192. It has 77 protons and 115 neutrons in its nucleus (77 + 115 = 192). When an electron is ejected as a beta particle, one neutron is converted to a proton.

The new atom now has 78 protons and 114 neutrons. The A number remains the same, (78 + 114 = 192), however the Z number is now 78 instead of 77. The iridium atom has changed to platinum - Pt-192.



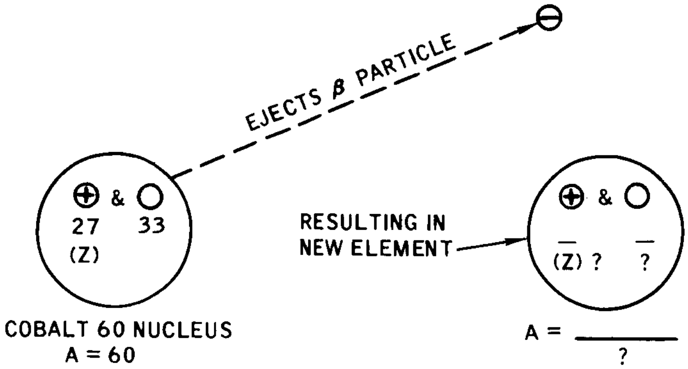
Beta particle decay results in a new element having one more proton (Z number) than the original, however the A number will remain the same.

Turn to the next page

From page 2-10

The radioactive isotope of cobalt, Co-60, is another isotope that decays by emission of a beta particle.

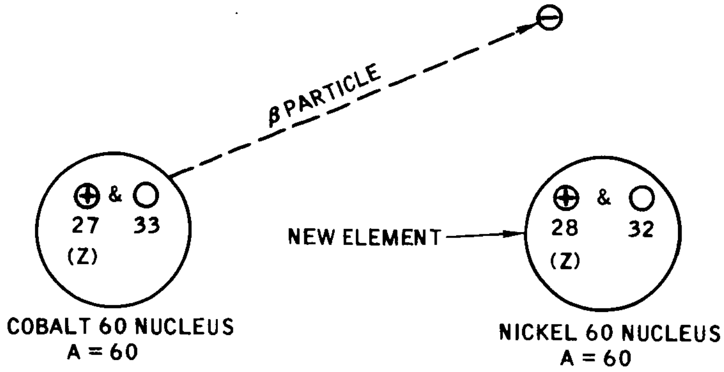
An atom of cobalt 60 contains 27 protons and 33 neutrons



When the atom disintegrates, a beta particle is ejected. Can you fill in the blanks above for the resulting atom?

Turn the page for the answer

From page 2-11



When the cobalt 60 atom emits a beta particle, it results in a new element, nickel 60 (Ni-60) that has 28 protons and 32 neutrons.

One neutron has lost an electron and becomes a proton.

The mass (A) number remains the same because the total number of neutrons and protons has not changed.

Turn to page 2-13

From page 2-12

So far, we have discussed only the emission of alpha and beta particles when radioactive atoms disintegrate.

Usually, although not necessarily, there is an additional energy adjustment in the radioactive atom when an alpha particle or a beta particle is emitted. <u>This energy adjustment results in the emission of a gamma (γ) ray.</u>

IT IS THE GAMMA RAY EMISSION THAT WE ARE INTERESTED IN.

Alpha particles and beta particles are not of any value in radiography. When working with radioactive isotopes, <u>only the gamma rays are of any use to the radiographer</u>.

To summarize the common modes or processes of radioactive decay, a radioactive atom, depending on its type can disintegrate by one of the following means:

1. Alpha emission only. (not of interest to us)
2. Beta emission only. (not of interest to us)
3. Alpha emission with associated gamma ray emission.
4. Beta emission with associated gamma ray emission.

There are other decay patterns that occur but they are not common and will not be discussed here.

Turn to page 2-14

From page 2-13

It should be mentioned here that any one radioactive isotope will decay according to a characteristic pattern. For example, a quantity of thulium 170 (Tm-170) will always emit beta particles within a certain predictable range of energies plus gamma rays of a specific energy. No other isotope has exactly the same decay pattern.

It should also be mentioned that the product of radioactive decay may also be radioactive. For example, when radium decays, it gives off an alpha particle and becomes the radioactive element radon. The radon in turn decays into other radioactive elements in a series of disintegrations until finally it becomes a stable isotope of lead, Pb-206.

All of the new elements that result from radioactive decay, whether they are radioactive or stable, are called DAUGHTER PRODUCTS of the original radioactive isotope.

Turn to page 2-15

We don't want to confuse the issue any more than it already is, however, some of you may be asking the question, "Where is the energy coming from that is given to the atomic particles that are ejected and where does the energy originate that is given off as gamma rays? Are we getting something for nothing?"

If you are interested, here is a simplified answer.

Do you remember seeing this equation before?

$$E = mc^2$$

This equation was furnished by a giant of our times, Albert Einstein. It means that energy and mass are interchangeable. In the equation, E is energy, m is mass, and c is the speed of light.

Obviously, c^2, is a very large number. This means that a very small mass, m, could be converted into rather high energies. This is the basis on which the atomic and hydrogen bombs work - the conversion of nuclear mass into energy.

In the case of radioactivity, the "mass loss" in the nucleus that results in energy emission is extremely small and insignificant. The mass (A) number of the atom is not affected by such slight changes in mass.

Turn to page 2-16

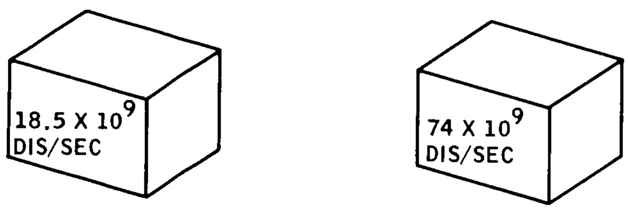
From page 2-15

Now that you have an idea of how radioactive isotopes disintegrate or decay, let's talk about how radioactivity is measured.

The basic unit for describing the activity (radioactivity) of a quantity of radioactive material is the "curie," named after the discoverer of the element radium.

A quantity of radioactive material is said to have an "activity" of <u>one curie</u> (C) when 37 billion of its atoms disintegrate in one second. (In scientific terms, this is written, $1C = 3.7 \times 10^{10}$ disintegrations/sec. or 37×10^9 disintegrations/sec.)

Let's say it another way. Given a chunk of radioactive material (source) of any size, we know that some of the unstable atoms are going to disintegrate or decay every second. If the rate of disintegration happens to be <u>37 billion atoms each second, the source has an activity of one curie</u>. If more than 37 billion atoms decay in one second, the source has an activity greater than one curie and if fewer than 37 billion decay, the activity is less than one curie.



Consider the two radioactive sources shown above. One decays at a rate of 18.5 billion disintegrations per second and the other at the rate of 74 billion disintegrations per second. What are their activities in curies?

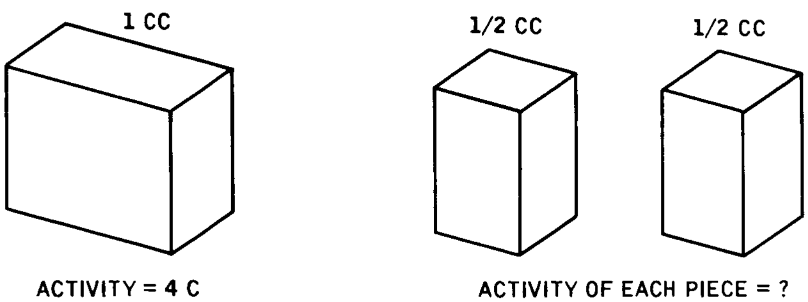
1/2 and 2 curies - page 2-17

There isn't enough information given. I would have to have the dimensions of the sources - page 2-18

You say that the two sources have activities of 1/2 and 2 curies.

Very good. We know how many disintegrations per second take place in each, so it is a simple matter to find the activities in curies.

Now let's take the case of a source with a volume of 1 cubic centimeter (cc). We'll say it has an activity of 4 curies. If we cut the source into two equal parts of 1/2 cc each, what will be the activity of each piece?



2 curies - page 2-19

4 curies - page 2-20

From page 2-16

You say that you need the dimensions before you can determine the activity of the two pieces.

Sorry. All the information you need is given in the problem. Remember, 1 curie equals 37 billion disintegrations per second (37×10^9 dis/sec). There is nothing in the definition of a curie that specifies the size of the source; it could be the size of a match head or the size of a melon. If it disintegrates at the rate of 37 billion atoms per second, it has an activity of 1 curie.

In our problem we had 2 sources, one that decays at a rate of 18.5 billion (18.5×10^9) disintegrations per second and the second at 74 billion (74×10^9) disintegrations per second. Therefore they have activities of 1/2 and 2 curies, respectively.

Turn to page 2-17

Excellent. Each piece has an activity of 2 curies. You apparently understand that by cutting the source in half, the number of atoms in each piece is half of the original; therefore, the number of disintegrations per second in each piece is half of the original.

On rare occasions you may be concerned with extremely small radioactive sources in radiographic work. There are sub-curie units to describe the activity of such sources. A millicurie (mc) is 1/1000 of a curie, and a microcurie (uc) is 1/1,000,000 of a curie.

Notice that in these discussions about "activity" of a radioactive source, we have talked about "disintegrations" of the atoms and not about the resulting radiation. As we mentioned before, each radioactive source has its own peculiar pattern of decay. One disintegration in a radioactive source doesn't necessarily mean that one gamma ray is emitted.

For example, in a Co-60 source, each atom decays by emitting a beta particle. Almost immediately, additional energy adjustments are made in the atom and two gamma rays are emitted. Each of the gamma rays has a certain energy that is always the same. In the case of C0-60, then, each disintegration results in two gamma rays.

Let's take another example, Tm-170. When a thulium source decays, approximately 1/4 of its atoms emit beta particles and an associated gamma ray. About 3/4 of the atoms emit beta particles with no associated gamma ray. Tm-170 always decays in this pattern. So, as a gamma ray producer, Tm-170 is not as efficient as Co-60, however it has other characteristics that make it useful in radiography.

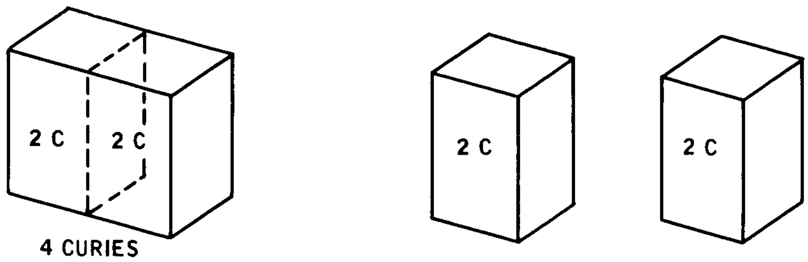
The point we are trying to make is that although the activities of different isotopes may be the same, the number of gamma rays that result from the disintegrations may be quite different.

Turn to page 2-21

From page 2-17

You say that when a 4 curie source is cut in two, each half will also have an activity of 4 curies.

Remember that activity is a measure of the actual number of atoms that disintegrate in one second. When you cut the number of atoms in a source in half, doesn't it seem reasonable that the number of atoms that will disintegrate will also be cut in half?



Turn to page 2-19

We have learned that the activity of a radioactive source is a measure of the number of disintegrations that take place each second. We also know that activity varies as the size of the source changes.

Given two different sources, chances are that one will be more active than the other. From what we have discussed so far, we can't tell which of the two is actually the better source - which one is actually more productive of radiation. One may have more activity simply because it is larger than the other.

You've heard boxing fans compare two fighters with, "Pound for pound, he's a better man." With radioactive sources we compare activities "gram for gram."

The activity, in curies, of 1 gram of any radioactive source is known as the SPECIFIC ACTIVITY of the source.

Remember, to be specific, you need more than just the activity (curies), you need the curies per gram (C/gr).

For example, if 2 grams of a cobalt 60 (C0-60) source has an activity of 50 curies, the specific activity of the C0-60 source is 25 curies per gram (25 c/g).

If 4 grams of iridum 192 (Ir-192) shows an activity of 1400 curies, what is the specific activity (c/g)?

specific activity is 1400 c/g - page 2-22

specific activity is 350 c/g - page 2-23

From page 2-21

We apparently didn't make our point clear. 1400 curies is the total activity of 4 grams of the Ir-192. However, we are trying to determine the activity of just 1 gram of the Ir-192.

In order to do this, we must divide 1400 by 4. The result, 350, is the specific activity in curies per gram (c/g).

Turn to page 2-23

Right. If 4 grams of Ir-192 has an activity of 1400 c, then 1 gram has an activity 1/4 of that, or 350 c. The specific activity of the Ir-192 is 350 c/g.

Let's try some more.

A. Six grams of an isotope has an activity of 90 curies

B. Two grams of an isotope has an activity of 2000 curies

C. 1/2 gram of an isotope has an activity of 750 curies

How would you arrange these isotopes in descending order of specific activity (highest specific activity first, etc.)?

B - C - A -- page 2-24

C - B - A -- page 2-25

You arranged the isotopes in B - C - A order.

Sorry. Either we didn't make clear what it is we want or your arithmetic is rusty.

Specific activity is the number of curies in 1 gram of the isotope. When you have other than 1 gram of radioactive material, you must divide the number of curies by the number of grams.

For example, if 3 grams of an isotope has an activity of 30 curies, the specific activity of that particular source is 30 c ÷ 3 g or 10 curies per gram. Or, given a source of 12 curies activity that weighs 1/2 gram, the specific activity is 12 c ÷ 1/2 g or 24 curies per gram.

Return to page 2-23 and give another try.

From page 2-23

You said C had the highest specific activity, followed by B and A. Right you are.

C. 750 c ÷ 1/2 g = 1500 c/g

B. 2000 c ÷ 2 g = 1000 c/g

A. 90 c ÷ 6 g = 15 c/g

In the family of isotopes commonly used for radiography, specific activity is important because it is an indication of the size of the radioactive pellet or "pill" (source) that will be required to furnish the necessary activity to do a radiographic inspection.

If the specific activity is low, it would mean that the pellet or pill size would have to be too big to give good radiographic results in some applications. You will get more on this subject in Volume 4.

Turn to page 2-26

Let's take another look at the decay process in a radioactive isotope.

Practically speaking, there is no such thing as a pure chunk of a radioactive isotope. Even if it were possible to completely separate a radioactive isotope from its surrounding materials, the purity of the piece would last but an instant, because some of the atoms would immediately start to decay into other isotopes. These new isotopes then become contaminants and the original isotope would no longer be pure.

Every radioactive isotope has its own pattern of decay. Not only does it decay by giving off various energies of different particles or rays as we've already discussed, but it decays at a rate that is characteristic of the isotope. Some isotopes decay quite rapidly, therefore have a high specific activity. Others decay at a very slow rate, therefore have a very low specific activity.

The rate at which a radioactive isotope decays is commonly measured in "half-life."

The half-life of an isotope is the time it takes for 1/2 of the atoms of the isotope to disintegrate.

Turn to the next page

Every radioisotope has its own peculiar half-life. Half-lives for various radioisotopes range from a few microseconds to many thousands of years.

For example, the half-life of cesium 137 (Cs-137) is 30 years. This means that at the end of 30 years, 1/2 of the cesium 137 atoms in a source would have disintegrated leaving 1/2 of the original atoms intact. It doesn't make any difference how much Cs-137 we start with - only 1/2 would be left at the end of a half-life, 30 years.

What fraction of the original Cs-137 atoms would remain in a source after 90 years?

1/3 would remain ------------------------------------ 2-28

1/6 would remain ------------------------------------ 2-29

1/8 would remain ------------------------------------ 2-30

You say that after 90 years, 1/3 of the Cs-137 atoms would remain.

You made a bad pick. From your answer it would appear that you recognize that 90 years is equal to 3 half-lives for Cs-137, but you didn't quite know how to apply that fact to the problem.

In one half-life, the number of atoms is reduced to 1/2. In the second half-life, the 1/2 that remains is again cut in half leaving 1/4 of the original Cs-137 atoms.

Can you take it from there? Turn back to page 2-27 and make another choice.

You feel that after 90 years, 1/6 of the Cs-137 atoms would remain.

You almost have it but your arithmetic is off. You apparently realize that 90 years is equal to 3 half-lives of Cs-137 and in trying to couple this with the fact that 1/2 the atoms remain after one half-life, you came up with 1/6.

Take a closer look. At the end of one half-life, 1/2 of the Cs-137 atoms remain. At the end of the second half-life, 1/2 of the 1/2, or 1/4, of the atoms remain. At the end of the third half-life, 1/2 of the 1/4 remains.

Turn back to page 2-27 and make another choice.

You have the idea. 90 years equals 3 half-lives of Cs-137.

$$1/2 \times 1/2 \times 1/2 = \frac{1 \times 1 \times 1}{2 \times 2 \times 2} = 1/8$$

In speaking of the effect of time on the radioactivity of a source, we don't ordinarily speak of the "number of atoms remaining." Instead, we measure the effect of time by referring to the reduced activity of the source.

Since at the end of a half-life, only half of the original number of atoms of the isotope remain, the source will be only half as active. In other words, the source will have only half as many curies as it originally had.

The half-life of thulium 170 (Tm-170) is 130 days. If we start with 50 curies of thulium 170 (Tm-170), what will be the activity of the Tm-170 at the end of 260 days?

12.5 curies ------------------------------------ page 2-31

50 curies ------------------------------------ page 2-32

You say that the original 50 curies of Tm-170 will be reduced to 12.5 curies after 260 days.

Very good. Tm-170 has a half-life of 130 days, therefore, 260 days is equal to 2 half-lives.

1/2 of 50 is 25, and 1/2 of 25 is 12.5

A source with a short half-life will drop below a practical level of activity in a relatively short time. In radiography this is an important consideration since it means that the source must be replaced fairly often.

Take the isotope Ir-192. It has a half-life of 75 days, just about as short as is practical to use. Its activity will drop to less than 1 percent of its original value in about 1 1/2 years. Ir-192 has other qualities, however, that make it a valuable source for radiographic work. You'll hear more about these qualities later.

On the other hand, radium 226 (Ra-226) has a very long half-life of 1620 years. It will lose less than 1 percent of its activity in 20 years.

Here are the half-lives of several of the common radioisotopes being used today for radiography -

Radium 226 (Ra-226)	1620 years
Cesium 137 (Cs-137)	30 years
Cobalt 60 (Co-60)	5.3 years
Thulium 170 (Tm-170)	130 days
Iridium 192 (Ir-192)	75 days

Turn to page 2-33

You say that after 260 days the Tm-170 source will still have an activity of 50 curies.

Careful now. We solve this problem in the same manner that we solved the problem about what fraction of radioactive atoms remain. The number of curies drops to 1/2 of its previous value at the end of each half-life.

First, how many half-lives of Tm-170 are there in 260 days? Now compute the number of curies remaining.

Return to page 2-30 and make a new choice.

From page 2-31

Here's a summary of the facts we've discussed in this Chapter.

First, Isotopes of the same element have the same number of protons in the nucleus (same Z number), but different numbers of neutrons (different A numbers).

Second, Many new artifical radioactive isotopes have been created in recent years by bombarding stable atoms with swarms of neutrons in a nuclear reactor.

Third, The process of creating new radioactive isotopes by neutron bombardment is called "activation."

Fourth, Radioactive atoms are unstable atoms that seek to stabilize themselves by emitting particles or electromagnetic energy.

Fifth, When a radioactive atom gives off particles or energy it is said to decay or disintegrate.

Sixth, When radioactive atoms decay they emit alpha particles (2 protons and 2 neutrons), beta particles (nuclear electrons), or gamma rays.

Seventh, Alpha decay results in the reduction of the atom's Z number by 2 and the reduction of its A number by 4.

Eighth, Beta decay results in the increase of the atom's Z number by 1. The A number remains the same.

(Continued on page 2-34)

Ninth, Gamma rays (pure energy) are emitted as the result of associated energy adjustments within the atom when an alpha or beta particle is emitted.

Tenth, Every radioisotope has its own peculiar decay pattern.

Eleventh, All new elements that result from radioactive decay are called daughter products.

Twelfth, One curie of radioactive material is that amount that will provide 37 billion disintegrations in one second.

Thirteenth, The curie is used to define the activity of a radioactive source with no reference to size of the source.

Fourteenth, Specific activity is the activity, in curies, in one gram of a radioactive source.

Fifteenth, The half-life of an isotope is the time it takes for one-half of its atoms to disintegrate.

Now turn to page 2-35 for a review.

From page 2-34

1. We know that the two atoms shown are atoms of the same element (hydrogen) because they both have the same ________________ number.

8. radioactive (unstable)

9. Radioactive or unstable isotopes "decay" or "disintegrate" by emitting tiny particles or bits of energy until they are again ________________.

16. curie

17. In a radioactive source having an activity of 1 curie, ______________ billion of its atoms will decay during a period of one ________________.

24. high, low

25. The activity of a source of iridium 192 will drop from 50 curies to 25 curies in a period of 75 days. Therefore, iridium 192 is said to have a ____________________ ________________ of 75 days.

1. atomic (Z)

2. The two hydrogen atoms shown have different __________ numbers because the total number of __________ and __________ in the nuclei are different.

9. stable

alpha particle

10. When a radioisotope emits an alpha particle, the __________ number of the atom is reduced by __________ and the __________ number is reduced by __________.

17. 37, second

18. A radioactive source in which 74 billion atoms disintegrate or decay in one second, has an activity of __________ __________.

25. half life

26. The half life of an isotope is the time it takes for 1/2 of the atoms of the isotope to __________.

2. mass (A), protons, neutrons

3. The two atoms shown are i____________ of the element hydrogen.

10. atomic (Z), 2
mass (A), 4

11. A neutron may be considered to be a combination of a ____________ and a ____________.

18. 2 curies

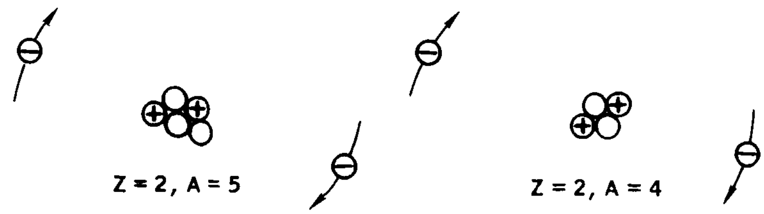
19. The activity of a radioactive source will change if the ____________ of the source is changed.

26. disintegrate (decay)

27. Every radioactive isotope has its own peculiar rate of decay, or in other words, a characteristic ____________ ____________.

3. isotopes

4. The two atoms shown are different ____________ of the same ____________.



11. proton, electron

⊖ beta particle

12. When a radioisotope emits a beta particle, the ____________ number is increased by ____________, but the ____________ number remains the same.

19. size

20. A radioactive source having a volume of 1 cubic centimeter will have ____________ the activity of a radioactive source of 1/2 cubic centimeter cut from the same piece of radioactive material.

27. half life

28. The half life of cobalt 60 is 5.3 years. A cobalt 60 source with an activity of 80 curies will decay to 20 curies in ____________ years.

[redacted])

4. isotopes, element

5. New isotopes of the same element can be created by adding______________ to atoms of the basic element thus changing the______________number.

12. atomic (Z), 1, mass (A)

13. Usually, when an alpha particle or beta paricle is emitted from a radioactive atom, an additional energy adjustment is made. This energy adjustment results in the emission of a______________ray.

20. twice (double)

21. The number of curies of activity of one gram of any radioactive material is known as the______________ activity of that particular material.

28. 10.6 years

29. Now turn to Chapter 3 and continue.

5. neutrons, mass (A)

6. Nuclear reactors give off large quantities of neutrons, therefore they are a good place to make new_______________ of basic elements.

13. gamma (γ)

14. Only a few radioactive isotopes have the necessary characteristics to make them useful in the field of _________________.

21. specific

22. If one gram of the radioactive isotope iridium 192 has an activity of 80 curies, the source has a specific activity of _____________ curies per gram.

6. isotopes

7. The process of creating artificial radioisotopes by adding neutrons to the nuclei of stable atoms is called ________________.

14. radiography

15. "Curie" is the unit used to measure the ________________ of a radioactive source.

22. 80

23. If 3 grams of cobalt 60 has an activity of 120 curies, the source has a specific activity of ________________________ per ________________.

7. activation

8. Isotopes that are not stable, that is, have a tendency to change form, are said to be_______________.

Return to page 2-35, frame 9.

15. activity

16. A radioactive source is said to have an activity of one_______________when 37 billion of its atoms decay or disintegrate in one second.

Return to page 2-35, frame 17.

23. 40 curies per gram.

24. Some radioactive isotopes decay rapidly, therefore have a _______________ (high) (low) specific activity. Others decay slowly, therefore have a _______________ (high) (low) specific activity.

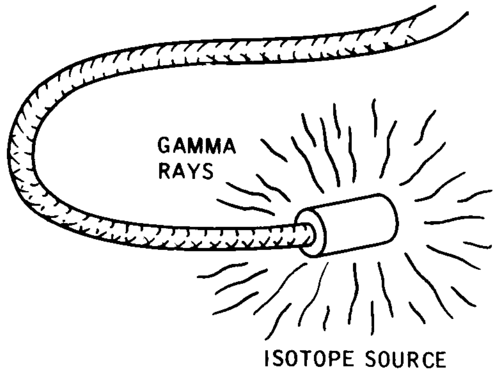
Return to page 2-35, frame 25.

CHAPTER 3 — CHARACTERISTICS OF X-RAYS & GAMMA RAYS

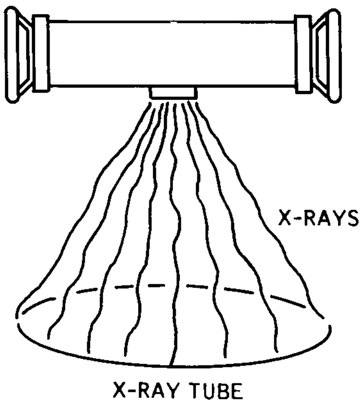
In the first two chapters you've been given a little theoretical background on the structure of the atom and phenomenon of radioactivity. Now let's talk about X-rays and gamma rays specifically in order to better understand the nature of these rays.

Actually, there are two kinds of radiation used in radiography, gamma rays and X-rays. Gamma radiation, as you now know, is one of the products of nuclear disintegration or decay. X-rays are produced artificially in a high voltage electron tube.

EXCEPT FOR THEIR SOURCES, GAMMA RAYS AND X-RAYS ARE EXACTLY THE SAME KIND OF RADIATION.



SAME KIND OF ELECTRO-MAGNETIC RADIATION



In this chapter you will discover some of the characteristics of X-rays and gamma rays - those that are basic to the subject of radiography.

Turn to the next page.

X-rays and gamma rays are not bits of matter or particles as are alpha and beta radiation. They have no mass or weight. Instead they are waves of energy. They are invisible, have no odor, and cannot be felt. In other words, our normal senses cannot detect X-rays or gamma rays.

The fact that we cannot see or feel the rays should not be a reason to treat them lightly. X and gamma radiation can be very damaging to the human body as you will find out in Volume 2; however, by following established safety procedures, there should be no reason to be concerned when using these invisible tools.

Select the correct statement.

Although gamma rays cannot be felt, strong X-rays produce a faint tingling sensation on the skin - page 3-3

X and gamma radiation are identical types of radiation and cannot be detected by the body senses - page 3-4

You think that strong X-rays can be detected by a tingling sensation.

You couldn't have been paying very close attention when you read the first two pages of this chapter. First we said that X-rays and gamma rays are identical except for source. Why then should one produce a sensation and not the other? Next we told you that neither X or gamma radiation can be detected by <u>any</u> of our senses.

Please reread pages 3-1 and 3-2 and make a new selection.

[redacted]

From page 3-2

Right. X and gamma radiation are identical and cannot be detected by our senses.

Just what is this unseen force? X and gamma rays are part of what scientists call the "electromagnetic spectrum." Many of its neighbors on this spectrum are familiar to us. Here is the spectrum.

ELECTROMAGNETIC SPECTRUM

X-RAYS AND GAMMA RAYS	ULTRA-VIOLET RAYS	LIGHT	INFRA-RED (HEAT) RAYS	RADAR	SHORT WAVE RADIO	LONG WAVE RADIO

DECREASING ← WAVELENGTH → INCREASING

As we have indicated on the diagram above, X-rays and gamma rays are actually waves, as are all other members of the electromagnetic spectrum. Every point on the spectrum represents an electromagnetic wave of a different wave length. The lines between the general groupings are not precise divisions - each grouping phases into the next.

From an examination of the spectrum which of these statements is correct?

Short wave radio waves are shorter than X-ray waves - - - - - - - - - - - - page 3-5

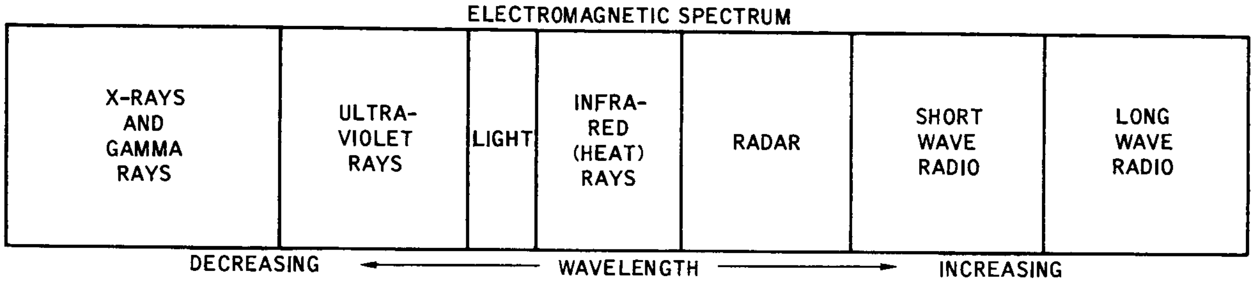
X and gamma ray waves are shorter than any other waves on the spectrum - page 3-6

From page 3-4

No. Short wave radio waves are not shorter than X-ray waves.

The term "short wave" radio may have mislead you. Actually "short" radio waves are very much longer than X-ray waves.

Here is the spectrum again.



At the bottom we have indicated that the wave length gets shorter as we approach the left end of the spectrum and longer as we approach the right end. Since X-rays are located at the extreme left end and radio waves at the right end, X-rays are shorter than radio waves, even "short" radio waves.

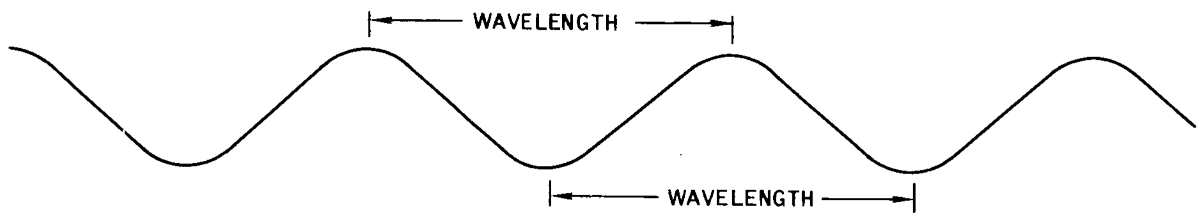
Turn to page 3-6

From page 3-4

You say that X and gamma ray waves are shorter than any other waves on the spectrum.

Correct. As we approach the left end of the spectrum the waves get shorter and as we approach the right end they get longer.

The waves we are talking about may be represented like this -



The distance between peaks of the waves or troughs of the waves is the wavelength.

These waves vary tremendously in length from one end of the spectrum to the other. Some radio waves at the right end of the spectrum are several miles long while X and gamma rays at the left end of the spectrum are measured in "angstrom units," and fractions of angstrom units. An angstrom unit is equal to 0.00000001 (ten billionths) centimeter.

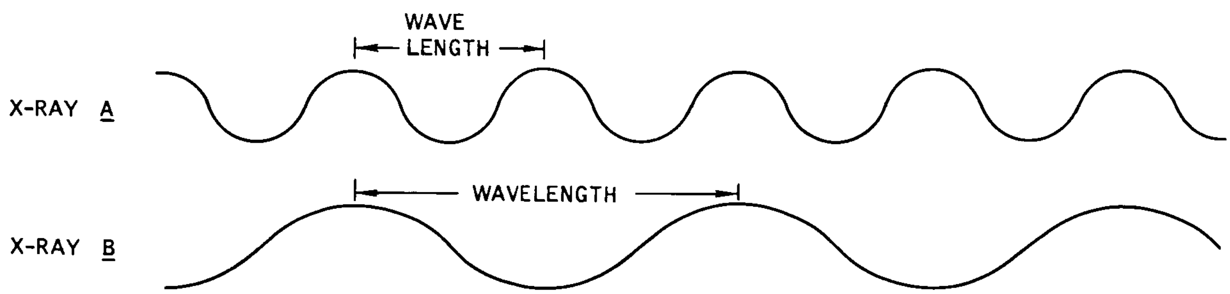
Since one centimeter (cm) is equal to 0.394 inch, you can see that an angstrom unit is an extremely short distance.

Turn to the next page

We have already stated that X-rays and gamma rays have no weight or mass. They also have no electrical charge. This means that they are not influenced by electrical fields and will therefore travel in straight lines.

Another characteristic of X-rays and gamma rays, one that is shared with all other members of the electromagnetic spectrum is the fact that they all travel at the same speed, 186,000 miles per second. This is the so-called "speed of light." Actually it is the speed of all electromagnetic radiation.

Here are two X-rays of different wave lengths. (greatly enlarged, of course).



Now, give some careful thought to the things we have discussed about X and gamma rays so far and see if you can pick out the correct statement below.

If we could count the number of waves from X-ray A and X-ray B (above) that pass a given point in one second, we would find that —

the number of A waves and B waves is the same - - - - - - - - - - - - - - page 3-8

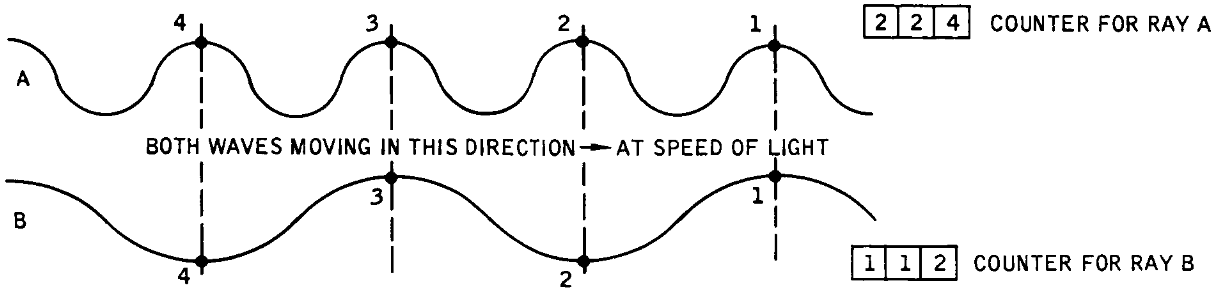
more A waves pass than B waves - page 3-9

From page 3-7

You feel that the same number of A waves and B waves would pass a given point in one second.

This isn't the case; here's why.

Remember we said that <u>all</u> electromagnetic waves travel at the speed of light, 186,000 miles per second?



This means that any and every point on each wave travels at the speed of light.

Point 1 on ray A moves at the same speed as point 1 on ray B.

Point 4 on ray A moves at the same speed as point 4 on ray B.

And all points in between move at the same speed.

Notice, then, that as the waves move - <u>at the same speed</u> - Counter A will record <u>more</u> waves in one second than Counter B because two A waves (in this case) will pass for every one B wave that passes.

Turn to page 3-9

From page 3-7

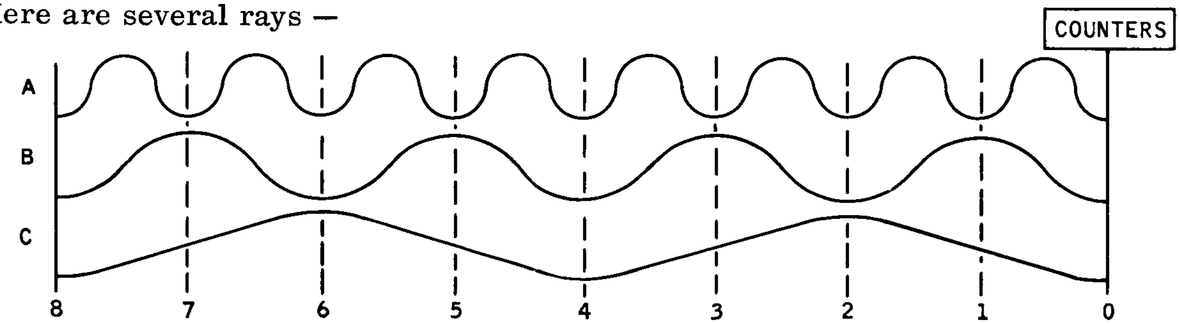
You picked, "more A waves pass than B waves."

Excellent. You recognize the fact that every point on the two rays will move with the speed of light, therefore more A waves will pass a given point than B waves.

If this concept isn't clearly fixed in your mind, we suggest that you turn to page 3-8 for an expanded discussion before you continue.

Let's go on. The number of electromagnetic waves that pass a given point in one second is called the "frequency" of that particular ray. Instead of labeling frequency as "waves per second" we say "cycles per second," a cycle being one complete wave, trough-to-trough or peak-to-peak.

Here are several rays —



Assume that the 8 segments of all three rays will pass the counter in one second. What is the frequency of each ray in cycles per second?

A = 8 c.p.s., B = 4 c.p.s., C = 2 c.p.s. ------------------ page 3-10

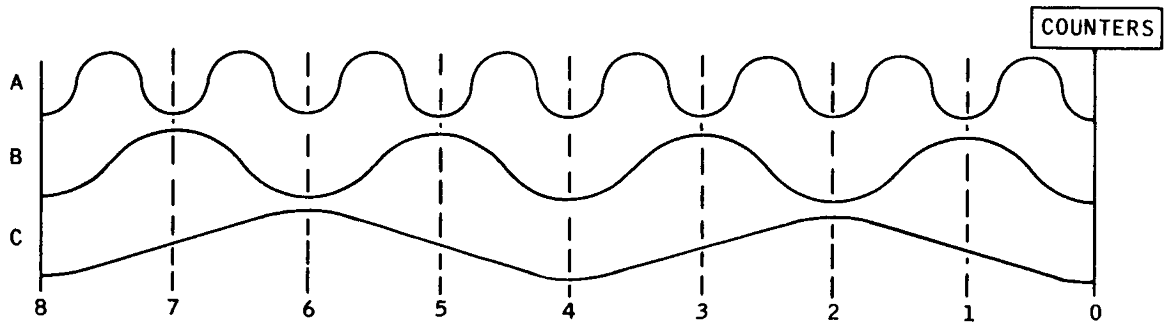
A = 16 c.p.s., B = 8 c.p.s., C = 4 c.p.s. ------------------ page 3-11

From page 3-9

You answered, "A = 8 c.p.s., B = 4 c.p.s., C = 2 c.p.s."

Right. Ray A has 8 complete waves, B has 4 complete waves, and C has 2 complete waves.

Take a look at the same diagram.



Comparing the wave lengths of each ray, we see that B waves are twice as long as A waves, and C waves are twice as long as B waves.

Let's chart the facts we know about these waves.

	Wave Length	Frequency
Ray A	1 Unit	8 c.p.s.
B	2 Units	4 c.p.s.
C	4 Units	2 c.p.s.

Choose the statement you think is correct.

When the wave length of an electromagnetic wave increases,
the frequency of the wave decreases - page 3-12

If the frequency of an electromagnetic wave is doubled,
the wave length doubles - page 3-13

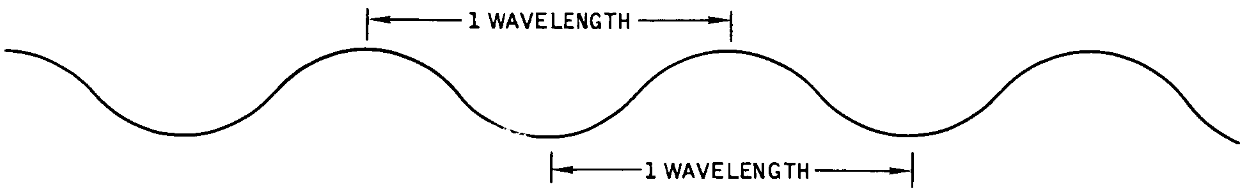
[redacted]

From page 3-9

Your answer, "A = 16 c.p.s., B = 8 c.p.s., C = 4 c.p.s."

Sorry, but you picked the wrong one.

You probably counted the troughs <u>and</u> the peaks in determining the number of waves in each ray. Remember - one wave length is the distance between successive troughs <u>or</u> successive peaks.



Turn back to page 3-9 and make another count

From page 3-10

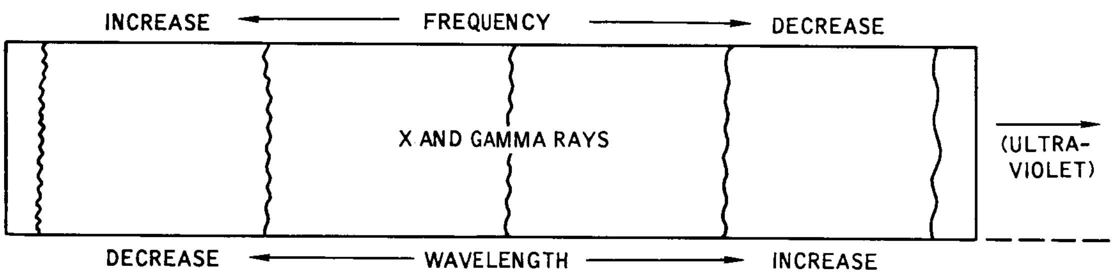
You picked, "When the wave length of an electromagnetic wave increases, the frequency of the wave decreases."

You picked the right answer. The frequency and wave length of electromagnetic waves are <u>inversely</u> <u>proportional</u>, which means that when one increases the other decreases by a proportionate amount.

Double one and take 1/2 of the other.

Triple one and take 1/3 of the other.

X and gamma rays are a subfamily of rays within the electromagnetic spectrum. If we were to take the "X-ray and gamma ray" segment out of the electromagnetic spectrum, we would have a sub-spectrum such as this —



Notice that on the left end of the spectrum, the wave lengths are short and have a high frequency. On the right end they are long and have a low frequency.

Turn to page 3-14

From page 3-10

You think that when the frequency of an electromagnetic wave is doubled, the wave length doubles.

That's not the answer we wanted.

Look at the chart again.

	Wave Length	Frequency
Ray A	1 Unit	8 c.p.s.
B	2 Units	4 c.p.s.
C	4 Units	2 c.p.s.

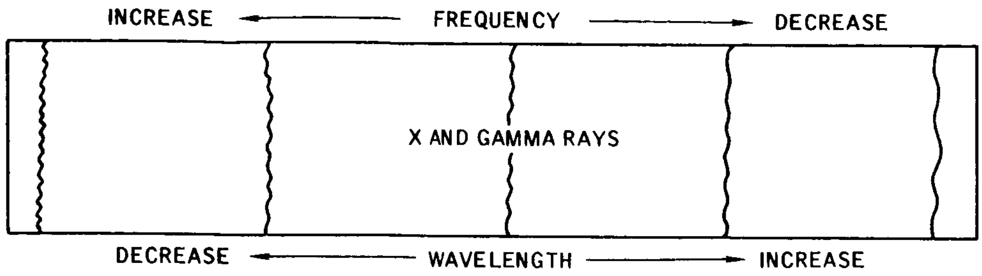
Start with the frequency of ray C, 2 c.p.s. The wave length for this ray is 4 units. Double the frequency and we have ray B, 4 c.p.s. The wave length for ray B is 2 units, half of ray C - not double.

As the frequency goes up, the wave length goes down.

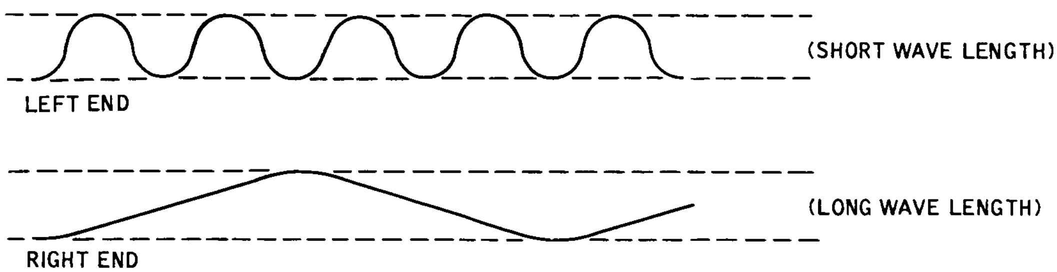
Turn to page 3-12

From page 3-12

Let's examine the X-ray/gamma ray spectrum a little closer.



If we take two X-rays, one from the left end of the spectrum and one from the right end, they might look something like this —

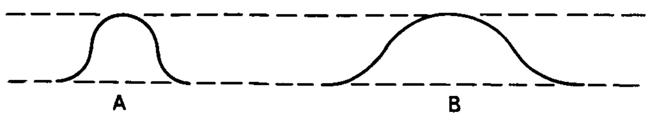


In addition to both of them being X-rays, the two rays have something else in common. Can you spot it?

Yes, the waves of both rays have the same "amplitude", or height.

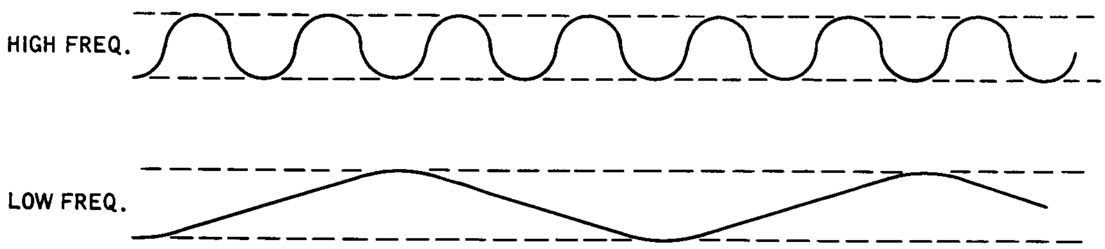
Turn to page 3-15

All X and gamma waves may be said to have the same amplitude or height.



The two waves shown above have different wave lengths and frequencies; however, they have the same amplitude, or the same energy.

Here are the two X-rays from the last page again. What could be said about them?



The two rays have equal amplitude therefore they have equal energy - - - - - page 3-16

The high frequency ray has more energy than the low frequency ray - - - - - page 3-17

From page 3-15

You say the two rays have equal energy because they have equal amplitude.

While it is true that each wave of the two rays has an equal energy, the two rays shown have different frequencies. The high frequency ray has 4 times as many waves as the low frequency ray, therefore 4 times more energy.

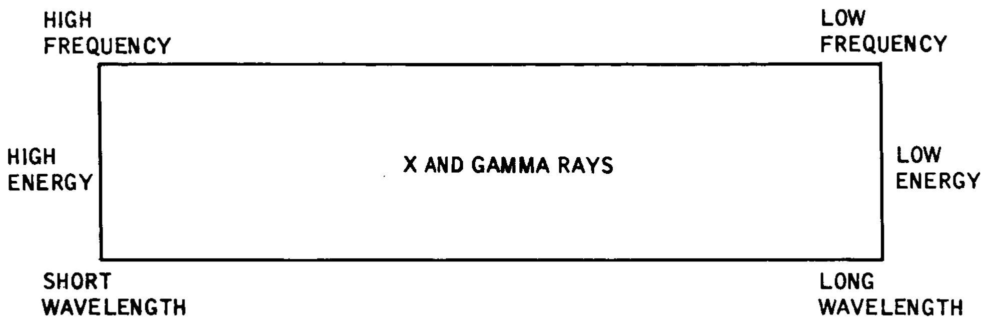
Turn to page 3-17

[redacted]

From page 3-15

Absolutely. The high frequency ray has more energy than the low frequency ray. Each wave has the same energy but in a high frequency ray there are more waves therefore more energy.

HIGH FREQUENCY, SHORT WAVE LENGTH, X AND GAMMA RAYS HAVE MORE ENERGY THAN LOW FREQUENCY, LONG WAVE LENGTH, RAYS.



The X-ray and gamma rays from the left end of the spectrum are high energy rays. These rays are sometimes called "hard" X-rays.

The X-ray and gamma rays from the right end of the spectrum are low energy rays. They are sometimes called "soft" X-rays.

Turn to page 3-18

From page 3-17

Before we go any further, let's discuss the method of measuring "energy." We'll be talking about energy more and more from this point on.

The energy of X-rays and gamma rays is measured in thousand electron volts (Kev) or million electron volts (Mev).

An electron volt is an amount of energy equal to the energy gained by one electron when it is accelerated by one volt.

For example, if one electron were accelerated by a potential of 100 thousand volts (100 Kv), the electron would have an energy of 100 thousand electron volts (100 Kev). If all of this energy were converted to electromagnetic radiation, the result would be a 100 Kev X-ray.

X-ray and gamma ray energies, typically used in radiography, run from a very few Kev to several Mev or more depending on the type of X-ray equipment being used or the particular radioisotope being used.

Turn to page 3-19

From page 3-18

What does the "energy" of an X-ray or gamma ray have to do with you as a radiographer? It is the foundation on which radiography is built.

It is the energy of X-rays and gamma rays that gives them the ability to penetrate solid objects.

Other rays from the electromagnetic spectrum, light rays for example, have the same amount of energy in each wave but their frequencies are too low to permit them to penetrate an object as X-rays do.

X-rays and gamma rays are all those rays at the left end of the electromagnetic spectrum that have sufficient energy to penetrate solid objects.

Choose the correct statement.

All X-rays and gamma rays have the same high energy, therefore are capable of penetrating solid objects - page 3-20

X-rays and gamma rays include a wide range of energies, therefore they vary in their penetrating abilities - page 3-21

From page 3-19

You chose, "All X-rays and gamma rays have the same high energy, therefore are capable of penetrating solid objects."

This statement is only partially true. All X-rays and gamma rays are capable of penetrating solid objects, but they do not have the same high energy.

Remember, energy varies as the frequency or wave length varies. The X-ray and gamma ray spectrum covers a wide range of frequencies therefore a wide range of energies.

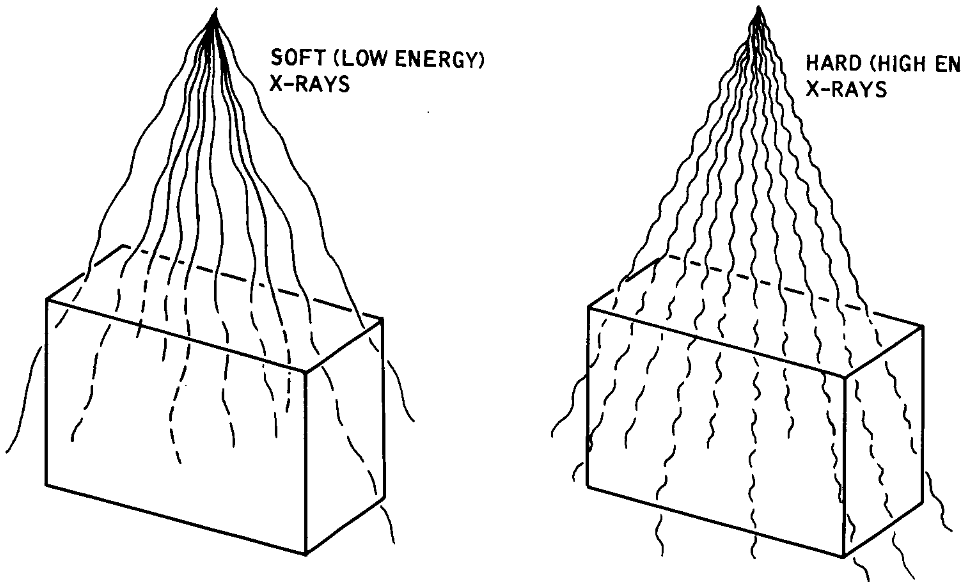
Granted, all of the energies are high in comparison to the rest of the electromagnetic spectrum, but within the X-ray/gamma ray group, every point on the spectrum represents a different energy.

Turn to page 3-21

From page 3-19

You picked, "X-rays and gamma rays include a wide range of energies, therefore they vary in their penetrating abilities."

Excellent! Low energy, or "soft," X-rays cannot penetrate as deeply as high energy "hard" X-rays.



Notice that all rays do not penetrate to exactly the same depth. We'll get into this a little later. The point we are making now is that the "average" hard ray will penetrate to a greater depth than the average soft ray.

Turn to page 3-22

From page 3-21

"Energy" is the key to a successful radiograph. Too little penetration or too much penetration of the specimen to be radiographed will result in an unsatisfactory radiograph. (You will learn why this is so in Volume 4.)

It would be nice if the radiographer had at his disposal a wide range of X or gamma radiation sources of various single energies. He could then pick the energy that would be best suited for the job. Such radiation, in which all rays are of a single wave length, or energy, is called MONOCHROMATIC radiation. Unfortunately, monochromatic radiation is rather rare.

X-rays, which if you remember are produced in a high voltage electron tube, are a heterogeneous mixture of a large number of rays of various energies. <u>The rays of maximum energy in this mixture are the result of the voltage that is applied to the X-ray tube, and are identified by this voltage</u>. For example, if 50 thousand volts (50 Kv) are applied to the X-ray tube, the resulting X-rays are a mixture in which the rays of highest energy are 50 thousand electron volt (50 Kev) X-rays. In addition, there are large quantities of X-rays of lower energies.

If 150,000 volts (150 Kv) were applied to an X-ray tube, the resulting X-radiation would consist of —

Monochromatic radiation with an energy of 150 Kev - - - - - - - - - - - - - page 3-23

X-rays with a maximum energy of 150 Kev plus many X-rays of lower energies - page 3-24

From page 3-22

You say that 150 Kv applied to an X-ray tube will result in monochromatic radiation with an energy of 150 Kev.

Sorry, we apparently didn't make clear the meaning of "monochromatic radiation." "Mono" indicates "single" or "one", therefore, radiation of a single frequency.

X-rays are by nature a mixture of many rays of various energies. The maximum energy of the X-rays in the mixture would in this case be 150 Kev, however they would not be monochromatic. If the 150 Kev X-rays could be separated from all the other rays of lower energy, then it would be monochromatic.

Turn to page 3-24

Yes. If 150 thousand volts (150 Kv) were applied to an X-ray tube, the resulting X-rays would be a mixture in which the maximum X-ray energy is 150 thousand electron volts (150 Kev).

Typically, there would be very few X-rays of maximum energy with most of the X-rays having energies something less than the maximum. There would also be some X-rays with very low energies, far below the maximum.

You'll learn more about this in Volume 3.

Turn to page 3-25

From page 3-24

Gamma rays from a radioactive isotope are not so much of a mixture of energies as are X-rays, in fact, in some cases they are monochromatic.

Every gamma producing isotope emits rays of one or more specific energies. These energies are always the same for any one isotope.

For example, Cobalt 60 (Co-60) always emits two hard gamma rays. One of these rays has an energy equivalent to the hardest ray that would be produced by a 1.33 Mev X-ray machine therefore it is called a 1.33 Mev gamma ray. The other ray is equivalent to the hardest ray that would be produced by a 1.17 Mev X-ray machine therefore it is called a 1.17 Mev gamma ray.

Co-60 always emits 1.33 Mev and 1.17 Mev gamma rays. The radiographer has no control over the energies of these rays - they are always the same.

What do you think would be the result if the size of a Co-60 source of a given specific activity were doubled?

The activity of the source would double, but the energy of the individual rays would remain the same - page 3-26

The activity of the source would double, therefore the energy of the individual rays would double - page 3-27

The energy of the individual rays would double, but the activity of the source would remain the same - page 3-28

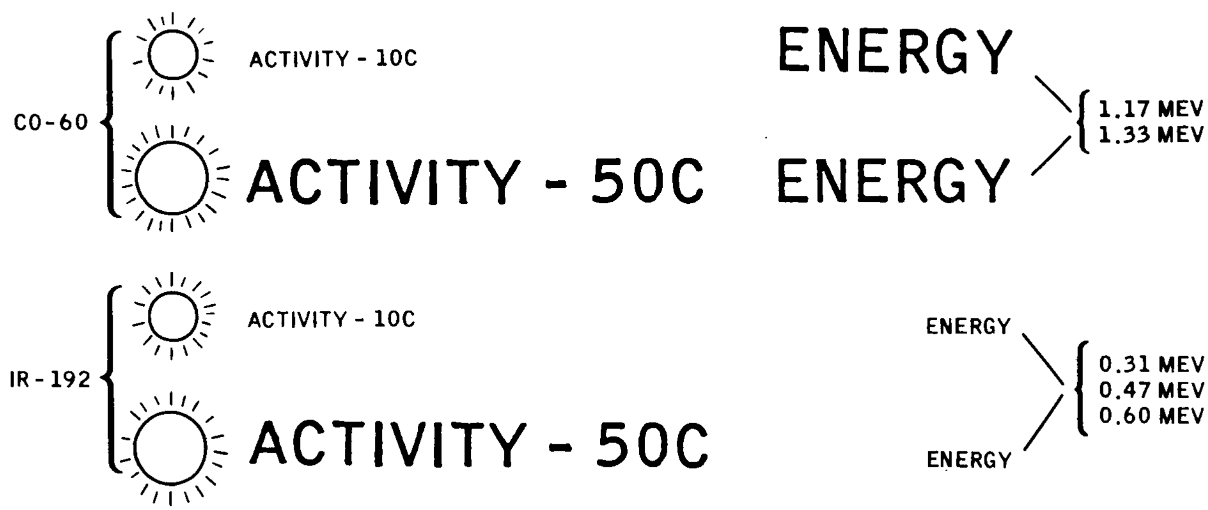
From page 3-25

You say that the activity would double but the energy would remain the same.

Very, very good. You remember what you learned about activity. Energy and activity are different things. They have no relationship to each other.

Activity is simply a measure of the number of disintegrations per second and varies with the amount of the isotope. It is measured in curies.

Energy is a measure of the penetrating ability of the individual rays and is independent of the amount of radiation. Energy is measured in Kev or Mev.



Note that the activities of Co-60 and Ir-192 vary with the size of the sources, but the energies of the gamma rays emitted remain the same. Only the number of rays changes - not the energy of the individual rays.

Turn to page 3-29

[redacted]

You say that when the size of a Co-60 source is doubled, the activity of the source doubles, therefore the energy of the rays would double.

No, your choice is not correct. You apparently remember what you learned about "activity" because that part of your answer is right. The activity or number of disintegrations per second will double when the size of the piece doubles.

The energy of the individual rays has nothing to do with the amount of radiation, therefore it would not be affected by the size of the source.

Turn back to page 3-25 and make another choice

[redacted]

From page 3-25

You say that when the size of a Co-60 source is doubled, the energy of the rays doubles but the activity remains the same.

Sorry, you have things turned around.

Remember in our earlier discussions about "activity," you learned that activity is a measure of the number of disintegrations per second. The curies of activity increases as the size of the source increases because there are more atoms to disintegrate.

The energy of the individual rays from a specific kind of radioactive isotope is always the same. They are independent of the size of the source (number of curies) and each isotope has its own peculiar energies that it radiates.

Turn back to page 3-25 for another try.

From page 3-26

Let's take a look at some of the gamma ray energies that are emitted by the common radioactive isotopes that you will be working with.

Cobalt 60 (Co-60) emits	1.17 Mev rays 1.33 Mev rays
Iridium 192 (Ir-192) emits	310 Kev (0.31 Mev) rays 470 Kev (0.47 Mev) rays 600 Kev (0.60 Mev) rays
Thulium 170 (Tm-170) emits	84 Kev (0.084 Mev) rays 52 Kev (0.052 Mev) rays
Cesium 137 (Cs-137) emits	660 Kev (0.66 Mev) rays

Some of these isotopes emit rays of other energies in addition to those listed, but in such small quantities that for radiographic purposes they may be ignored.

The isotopes listed will <u>always</u> emit rays with the energies shown. The <u>number</u> of these rays will vary depending on the number of curies, or activity, of the isotope being used.

Which of the isotopes listed would have the most penetrating radiation and which the least?

Cs-137 most penetration and Co-60 least- page 3-30

Co-60 most penetrating and Tm-170 least - - - - - - - - - - - - - - - - - - - page 3-31

From page 3-29

You picked, "Cs-137 most penetrating & Co-60 least."

Your answer is the wrong one. You probably missed the fact that the Co-60 energies are listed in "Mev" and not "Kev."

1 Mev equals 1000 Kev

Turn back to page 3-29 and take another look at the list then make a new choice.

From page 3-29

You say, "Co-60 most penetrating and Tm-170 least"

Right. Since Co-60 emits gamma rays with the most energy its rays are the most penetrating.

Tm-170 gives off gamma rays of the least energy therefore its rays are least penetrating.

You don't have to memorize the energies of these gamma rays but you should remember the approximate ranges. Cobalt 60 has very hard rays, iridium 192 and cesium 137 have moderately hard rays and thulium 170 has soft rays.

The gamma ray energies are fixed for each isotope. On the other hand, X-rays can be generated over an almost unlimited range. Depending on the equipment being used, the radiographer can select any energy he wishes from a few Kev to several Mev. However, in addition to the maximum energy he selects, he will also get all the energies below that value.

Turn to the next page.

From page 3-51

Now you are ready to start back through the book and read those upside-down pages.

From page 3-31

We have tried to make the point on the last several pages that the "energy" and "activity" of a radioactive source are different things and do not depend on one another.

Energy is determined by the wave length or frequency of each ray and is reflected in the penetrating ability of the ray. Energy is measured in Kev or Mev.

Activity of a radioactive source relates to the number of disintegrations that take place in one second. Activity is measured in curies.

Now let's extend our thinking a step further. Using what you know about the decay patterns of various isotopes, pick one of the following statements.

One curie of activity represents a precise number of gamma rays regardless of the type of radioisotope - page 3-33

One curie of activity represents a precise number of gamma rays in any one type of radioisotope - page 3-34

From page 3-32

Think again. Remember what we said about radioisotopes? Each one has its own peculiar decay pattern.

Although one curie of radioactive material represents 37 billion disintegrations per second, the number of gamma rays emitted depends on the particular isotope.

Turn to page 3-34

Very good. One curie is a precise measure of the number of disintegrations (37 billion/sec) regardless of the isotope, however, each isotope has its own peculiar decay pattern. Therefore we must know which isotope we are talking about in order to relate activity to numbers of gamma rays.

Here is our point. When dealing with any one isotope, the curie strength is not only a measure of the activity, but also a measure of the number of gamma rays emitted, or the intensity of the gamma radiation.

For example, the gamma intensity (number of rays) from a 5 curie Co-60 source can be doubled by using a 10 curie Co-60 source.

Or, the gamma radiation from a 50 curie Ir-192 source is 5 times as intense as the radiation from a 10 curie Ir-192 source.

However, the gamma radiation from 10 curies of Ir-192 is not twice as intense as the gamma radiation from 5 curies of Co-60.

Turn to page 3-35

From page 3-34

The curie strength determines the gamma radiation intensity for radioisotopes. We can compare these intensities directly when we are talking about two or more sources of the same isotope.

X-ray intensity (number of X-rays), as with gamma rays, has nothing to do with the energy of the individual rays. As we discussed earlier, X-ray energy is controlled by the voltage that is applied to the X-ray tube.

However, the intensity of the X-radiation (number of X-rays) is directly proportional to the current or amperage that is applied to the tube. (Later in the program you will find out why this is so.)

Let's see what this means —

The intensity of X-radiation from an X-ray tube will double if the current is doubled, say from 10 milliamps (ma) to 20 milliamps, provided the voltage (energy) remains the same.

From this discussion you can see that curie strength and current have a common meaning to the radiographer. They both determine radiation intensity or number of rays. They do not change the energy or penetrating ability of the individual rays.

Turn to page 3-36

From page 3-35

Let's review a little of what we've learned in this Chapter.

First, Except for their sources, X-rays and gamma rays are exactly the same kind of radiation.

Second, X-rays and gamma rays are waves of pure energy. They have no mass or weight and they travel at the speed of light.

Third, X-rays and gamma rays cannot be detected by our normal senses.

Fourth, X-rays and gamma rays are electromagnetic radiation.

Fifth, X-rays and gamma rays have very short wave lengths and very high frequencies in comparison to other members of the electromagnetic spectrum.

Sixth, Short wave length, high frequency X-rays and gamma rays have more energy than long wave length, low frequency rays.

Seventh, The energy of X-rays and gamma rays is measured in Kev and Mev. An electron volt is the amount of energy gained by an electron when it is accelerated by one volt.

Eighth, The energy of an X-ray or gamma ray determines its penetrating ability.

Ninth, Monochromatic radiation is radiation of a single wave length or energy.

(Continued on page 3-37)

Tenth, Any given gamma producing isotope always emits gamma rays of the same energy or energies.

Eleventh, X-ray machines produce a mixture of X-rays. The X-rays of highest energy are dependent on the voltage applied to the tube.

Twelfth, Gamma ray energies are determined by the type of isotope. Gamma ray intensity, or number of rays, is determined by the activity, or curie strength, of the isotope.

Thirteenth, X-ray energies are determined by the voltage applied to the X-ray tube. X-ray intensity is determined by the current, or milliamperage, applied to the tube.

Turn to page 3-38

From page 3-36

So far we have described X radiation and gamma radiation as being wavelike in character. They have wavelengths and frequencies that can be computed and they behave like waves - up to a point. About the turn of the century, researchers found that electromagnetic radiation had some characteristics that did not fit the wave theory. Sometimes the electromagnetic radiation acted almost like particles.

A new idea was presented that described electromagnetic radiation in terms of parcels or packets of energy. The parcels of energy were called "quanta." The idea of quanta is very useful in explaining some of the properties of electromagnetic radiation and today it is an accepted part of scientific knowledge on the subject.

The word "quanta" is not heard much anymore, instead the term PHOTON (fó-tawn) is more common. The words are interchangeable.

To the physicist, electromagnetic radiation is two things, waves or bundles of energy called photons. You will hear both terms used when discussing X-rays and gamma rays. So far as we are concerned in our study of radiography, the full scientific discussion of waves vs photons is not necessary - we will just accept the fact that X-rays and gamma rays are either or both.

In the following chapters we will often use the word photon because it is a more convenient term in many cases.

A word of caution to some of you. Don't confuse the word "photon" with "proton." A proton is a positively charged particle (⊕), while a photon is a parcel of energy with no mass or charge.

Please turn the page.

From page 3-38

1. Two types of electromagnetic radiation are used in radiography. They are ________________-rays and __________________ rays.

10. straight

11. All electromagnetic radiation travels at the same speed. This speed is commonly known as the __________________ _____ __________________.

20. energy

21. "Soft" X-rays is a term commonly used for _______________ energy X-rays. "Hard" X-rays is a common term for ______________ energy X-rays.

30. 1,330
(Note: 1 Mev = 1000 Kev)

31. "Activity" of a radioisotope is a measure of the number of __________ per seconds and varies with the _______________ of the isotope.

"Energy" of a radioisotope is a measure of the penetrating ability of the radiation and is independent of the amount of __________________.

1. X, gamma

2. X-rays and gamma rays are exactly the same kind of radiation. However, they have different ________________.

11. speed of light

12. Electromagnetic radiation is a wave form of energy. Every electromagnetic wave, regardless of its length, has the same ______________.

21. low, high

22. X-radiation or gamma radiation that is made up of rays of a single wavelength or energy is called mono______________ radiation.

31. disintegrations
amount (size)
isotope (radiation)

32. In radiography, the number of X-rays or gamma rays is commonly thought of as the ______________ of the radiation.

2. sources (origins)

3. X-rays and gamma rays are not particles of matter. They are bits or waves of ________________.

12. energy

13. Because all electromagnetic waves travel at the same speed, and because each wave has the same energy, a beam of electromagnetic radiation composed of short waves will have ______________ energy than a beam composed of long waves.

22. monochromatic

23. X-radiation consists of a mixture of many different rays of many different energies, therefore it would not be considered ________________.

32. intensity

33. The intensity of a gamma beam is a direct function of the activity, or number of ______________, in the source.

3. energy

4. X-ray and gamma rays have no mass or weight. They are invisible, have no odor, and cannot be felt.

True or False?

13. more

14. X-rays and gamma rays are composed of extremely short waves therefore they have more ____________ than visible light rays or infrared rays that are made up of longer waves.

23. monochromatic

24. Gamma radiation from a radioactive isotope may be monochromatic depending on the isotope. In most cases, however, even gamma radiation is not monochromatic. This means that the radiation is a mixture of two or more rays of different ________.

33. curies

34. The intensity of an X-ray beam is controlled by the ______________ in the X-ray tube.

4. True

5. X-rays and gamma rays are a wave form of energy that is part of a larger grouping known as the ________________ spectrum.

14. energy

15. Within the X-ray and gamma ray family, there is a wide variation of wave lengths. Therefore there is a wide variation of ________________.

24. energies

25. ______________ radiation consists of a mixture of a large number of different energy rays while ____________ radiation consists of one or a limited number of energy rays.

34. amperage (milli-
amperage, current)

35. Gamma rays from Cobalt 60 have a ___________ energy; those from iridium 192 and cesium 137 have a moderately ____________ energy; and those from thulium 170 have a ______________ energy.

5. electromagnetic

6. Ultraviolet rays, visible light rays, infrared rays, and radio waves, together with X-rays and gamma rays, make up the ____________ ____________.

15. energies

16. Some X-rays have more energy than others. This would indicate that X-rays can have different ____________ ____________.

25. X-, gamma

26. In an X-ray beam, the highest energy rays are dependent on the ____________ that is applied to the X-ray tube.

35. high, high, low

36. At times, electromagnetic radiation acts almost like particles rather than waves. For this reason, electromagnetic radiation is sometimes thought of as parcels of energy. These parcels are known as ____________.

6. electromagnetic spectrum

7. In the electromagnetic spectrum, the rays with the shortest waves are ________________ rays and ________________ rays.

16. wave lengths

17. "Frequency" of electromagnetic radiation is a measurement of the number of waves that pass a given point in one second. Radiation made up of very short waves would have a ________________ frequency.
(low) (high)

26. voltage

27. The term "Kev" means ________________ electron volts and "Mev" means ________________ electron volts.

36. photons (quanta)

37. Now turn to Chapter 4 and continue.

7. X-, gamma

8. Radio waves are relatively ________________ electromagnetic waves and X-rays are ____________________ electromagnetic waves.
(long) (short)

17. high

18. Frequency of electromagnetic radiation is inversely proportional to the wave length. This means that if the wave length were cut in half, the frequency would ____________________.

27. thousand (kilo), million

28. If 100 thousand volts (100 Kv) is used to produce X-rays, the hardest rays of the resulting mixture will have an energy of _______________.

8. long, short

9. The shortest waves on the electromagnetic spectrum are ____________ rays and ____________ rays.

18. double

19. High frequency, short wave length X-rays have ____________ energy than low frequency, long wave length X-rays.

28. 100 Kev

29. Gamma ray energies for any one isotope are always the same. This means that cobalt 60 always emits gamma rays of the same ____________.

9. X-, gamma

10. X-rays and gamma rays have no electrical charge. This means they are not influenced by electrical fields and will therefore travel in _______________ lines.

Return to page 3-39, frame 11.

19. more

20. The penetrating ability of an X-ray or a gamma ray is dependent on the _______________ of the ray.

Return to page 3-39, frame 21.

29. energy

30. Gamma ray energies are also measured in Kev and Mev. A gamma ray with an energy of 1.33 Mev would be equivalent to hardest ray that could be produced when _______________ Kv is applied to an X-ray tube.

Return to page 3-39, frame 31.

CHAPTER 4 — INTERACTION WITH MATTER - ABSORPTION AND SCATTER

In this chapter you will learn something of the effect of X and gamma radiation on matter and, conversely, the effect of matter on X and gamma radiation. Of all the material you have studied thus far, this is probably the most important. The entire subject of radiography hinges on an understanding of the interactions between X and gamma rays and matter.

We have learned that X and gamma rays are capable of penetrating all matter. We have also learned that the depth of penetration depends upon the energy of the rays - the higher the energy (shorter the wave length), the greater the penetration. Now let's consider another factor that determines the depth of penetration - the material being penetrated. (In the following discussions we will talk about X-rays, however, the same ideas are true for gamma rays).

You may not have thought of it before, but the air around you is matter. X-rays will penetrate air to a considerable depth, but as with any other material, air will eventually absorb the X-rays.

Consider a light metal, say aluminum. X-rays will penetrate aluminum also, but to a much lesser depth than air.

Now take a heavier or more dense metal, steel for example. X-rays will also penetrate steel, but not to the extent that they will penetrate aluminum.

From this discussion what would you suspect about the penetrating ability of X-rays in various materials?

X-rays penetrate steel less than any other material- - - - - - - - - - - - - - page 4-2

X-rays penetrate light materials better than they penetrate
dense materials- page 4-3

Wrong choice. Although X-rays will not penetrate steel as well as aluminum or air, there are other materials that offer a greater resistance to X-ray penetration.

The point here is that as materials of higher and higher density are used, the resistance to penetration increases.

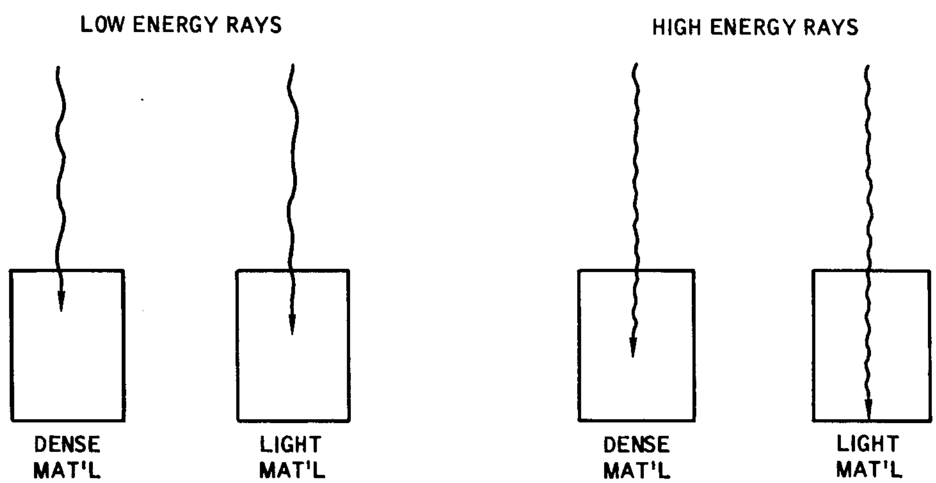
Turn to page 4-3 for additional discussion of this point.

From page 4-1

That's the idea. X-rays penetrate light materials better than heavy or dense materials. Or, in other words, the heavier, more dense, materials offer greater resistance to X-ray penetration.

This fact seems reasonable when you consider the larger number of targets blocking the path of an X-ray thru heavy materials. Atoms with a high Z number have more electrons in them than atoms with a low Z number. That is the reason lead is commonly used as a shielding material against X-rays. It has a high Z number - it's heavy and dense and X-rays cannot penetrate it as readily as most other materials.

So now we know that in addition to the energy of the X-rays that are used, penetration is also dependent on the density of the material being penetrated.



Turn to page 4-4

From page 4-3

But what happens to X-rays when they penetrate materials? We know that some of them go farther than others, but all of them must stop at some time.

These X-rays, or photons, are little packets of energy moving at the speed of light and when the photons stop, we know that something must happen. The photons' energy doesn't just disappear, it has to be transformed in some way. This is one of the basic laws of nature - energy can neither be created nor destroyed. It can be converted into a number of different forms but the energy is always there.

X-rays are <u>absorbed</u> by materials they penetrate by a process known as "ionization." The X-rays create "ions" in the materials they pass through and their energy is absorbed during the process.

<u>Basically, an ion is a CHARGED atom, group of atoms, or atomic particle of either positive or negative sign.</u>

If you removed an electron from a stable atom, could you call the incomplete atom an "ion"?

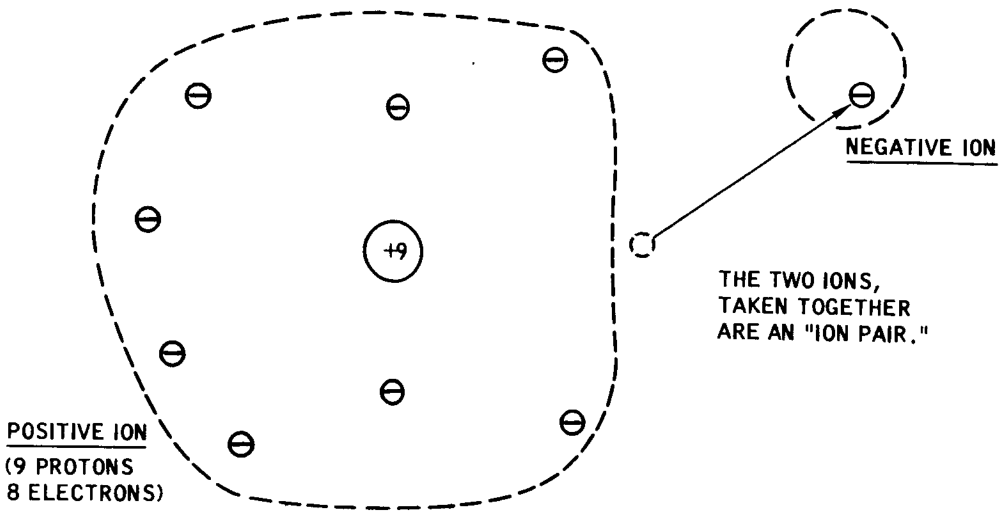
Yes - page 4-5

No - page 4-6

From page 4-4

Right. If you remove an electron from the atom, it becomes electrically incomplete. There are more protons (positive charges) in the nucleus than there are electrons (negative charges) to balance them. The atom has a plus one charge, therefore it is a positive ion.

Similarly, the electron that was removed is a negative ion as long as it exists by itself and doesn't combine with another atom.



An atom is held together by energy. This means that each electron is held in orbit by a quantity of binding energy. And in order to dislodge an electron from its atoms it will take energy at least equal to the binding energy.

Turn to page 4-7

From page 4-4

You don't think that an atom with one electron removed is an ion?

If you think about it a second you'll see that it does meet the requirement for an ion. With an electron removed, the atom is electrically unbalanced therefore it has a charge. A charged atom, group of atoms, or atomic particle is an ion.

Turn to page 4-5

When an X-ray "collides" with an electron in the penetrated material, it transfers some or all of its energy to the electron and knocks it out of its atom.

We say "collide" because this is one of those cases we talked about earlier in which X-rays act like particles. We should probably say that a photon collides with an electron.

Photons, any of those within the energy range that the radiographer is likely to be using, are absorbed by the substances they penetrate through the process of knocking electrons out of atoms. This is ionization, or the creation of ION PAIRS.

An ion pair consists of the two ions, one with a positive charge and one with a negative charge, that result from one ionizing action.

There are ways other than ionization in which photons are absorbed, but they involve photon energies outside the limits that the radiographer will normally use so we will ignore them.

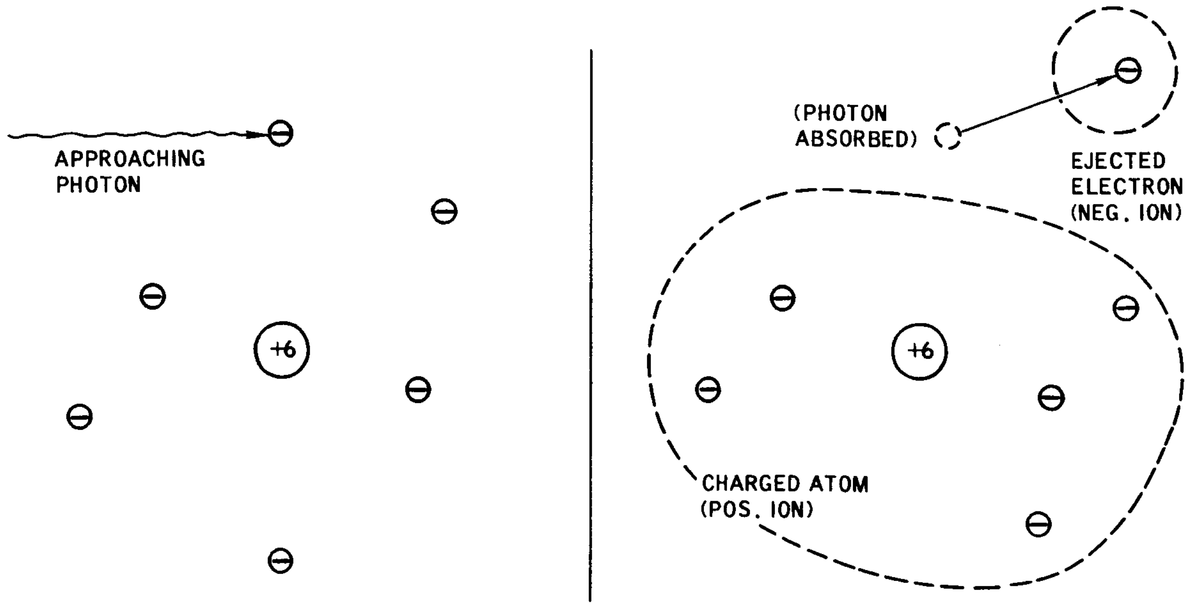
Turn to page 4-8

[redacted]

Ionization of atoms by X-rays takes place in two different ways - photoelectric effect and Compton effect.

Let's discuss photoelectric effect first.

Photoelectric effect occurs primarily with lower energy X-ray photons of 10 Kev to 500 Kev. It involves the complete absorption of the photon during the process of knocking an electron out of orbit.



PHOTOELECTRIC EFFECT

Let's take an example of photoelectric effect. A 100 Kev photon approaches an atom and collides with an electron that has a binding force of 50 Kev. The electron is ejected from the atom and becomes a negative ion. The atom from which the electron is removed is now a positive ion. The two ions are an ion pair. The photon disappears - it is completely absorbed.

But what happens to the rest of the energy from the photon - the difference between its initial energy of 100 Kev and the 50 Kev that is used to overcome the electron's binding energy? This is a tough one, but can you pick the correct answer?

It is given to the ejected electron in the form of speed - - - - - - - - - - - - - page 4-9

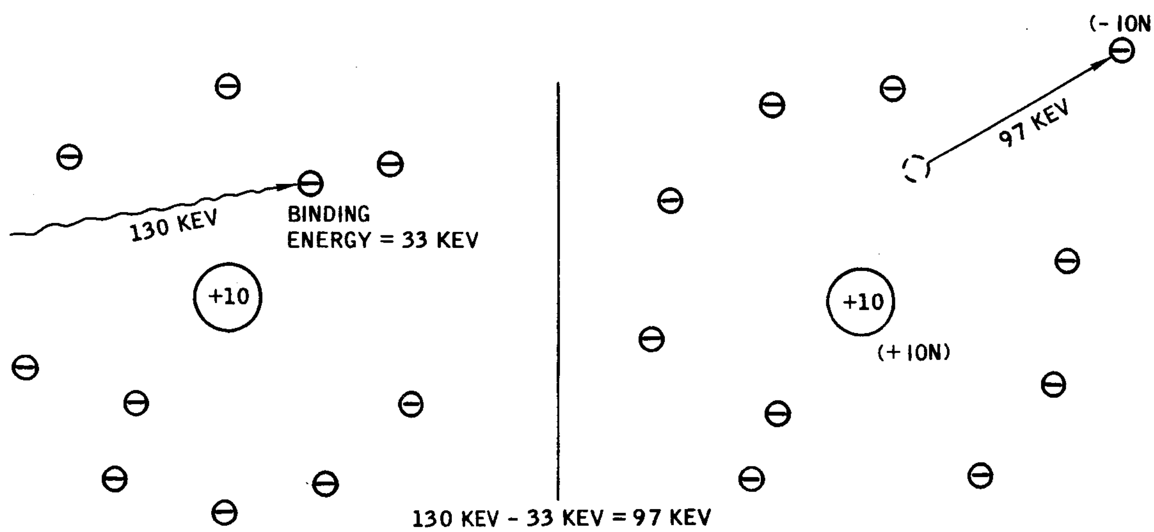
It is absorbed by the atom which then becomes radioactive - - - - - - - - - - - page 4-10

Excellent! You didn't have much to go on in making your choice, but your answer is correct.

The excess energy is given to the ejected electron in the form of "kinetic" energy, or speed. In our particular example, the ejected electron will have a kinetic energy of 50 Kev which means that it will be moving at a fair speed.

All the energy of the photon has been accounted for now and the photon ceases to exist. Remember that a photon is not a particle although it may act like one. When the energy is used, there is nothing left.

Here's another example of photoelectric effect.



PHOTOELECTRIC EFFECT

Again, all of the photon energy has been used in producing an ion pair. All electrons do not have the same binding energy. It depends on the element (Z number) and on the position of the electron in the atom. Those closest to the nucleus have a greater binding energy than those at the outer edges, therefore they require greater photon energy to remove them. The outer electrons are comparatively easy to eject.

Turn to page 4-11

As we said, this was a tough choice to make. If you recall, earlier in the book we said that atoms were activated, or made radioactive, by injecting <u>neutrons</u> into their nuclei.

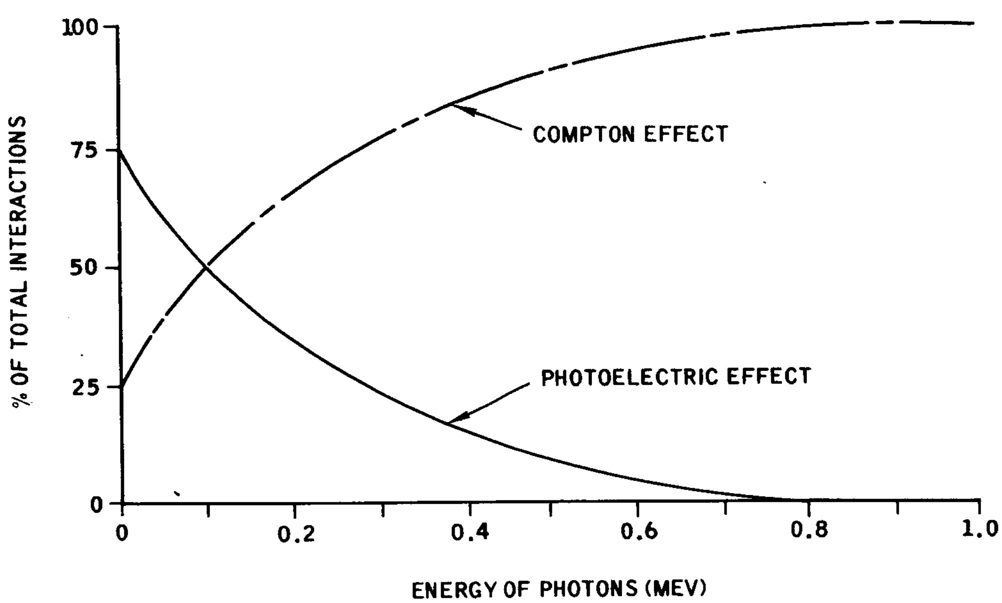
Atoms <u>cannot</u> be made radioactive by exposing them to the X or gamma radiation energies used in radiography.

The correct answer is, "It (the excess energy) is given to the ejected electrons in the form of speed."

Turn to page 4-9 for additional discussion.

Now let's consider Compton effect (or scattering as it is sometimes called). Compton effect is a logical extension of the photoelectric effect, the difference being that the initial photon energies are generally higher. When we start with higher photon energies, all the energy may not be utilized in removing and accelerating an electron. There may be energy left over.

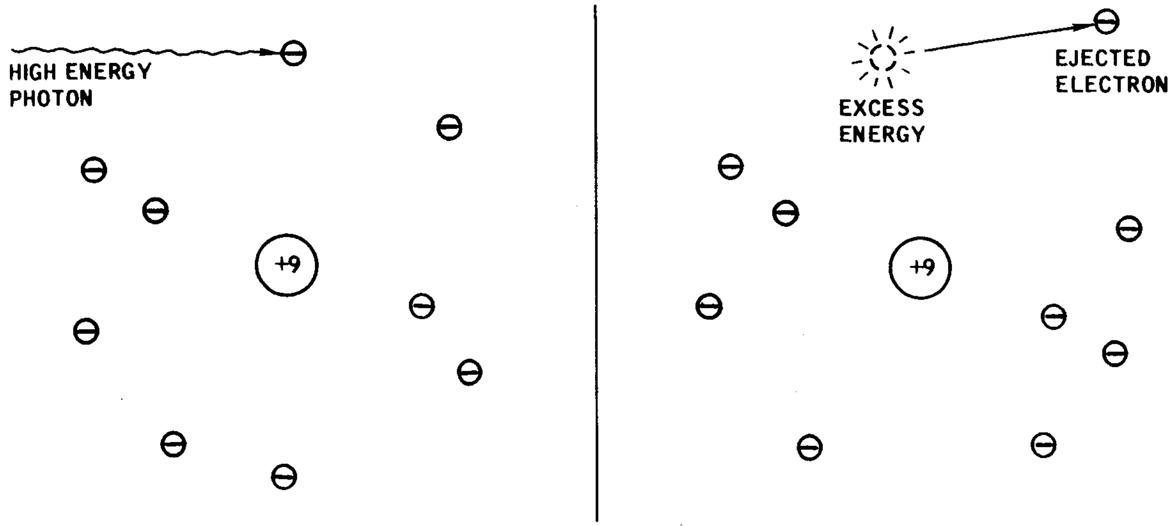
The Compton effect is common when photons fall in the 50 Kev to several Mev range. Notice that the energy range overlaps the photoelectric energy range. At very low photon energies, photoelectric effect is dominant, but it becomes less common as photon energies increase. Compton effect starts slowly at the lower energy levels and becomes dominant at about 100-150 Kev.



COMPTON EFFECT VS. PHOTOELECTRIC EFFECT

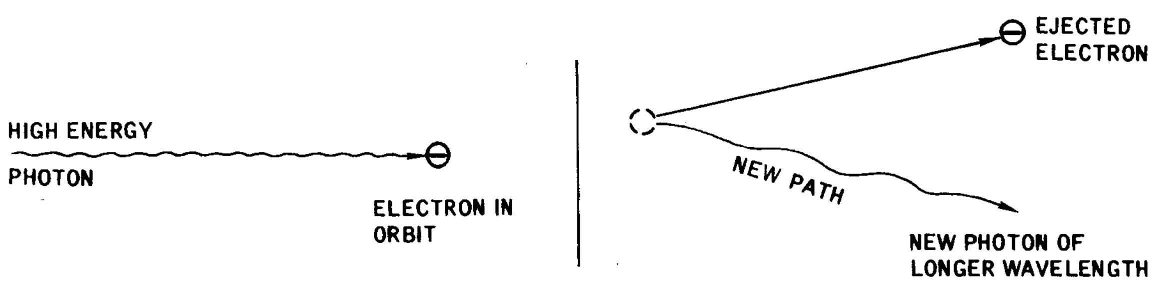
Turn to page 4-12

In the Compton effect, all of the energy of the photon is not absorbed by the electron. When the electron is ejected, there is still some excess, unused energy.



COMPTON EFFECT

This excess energy takes the form of a new photon that has a longer wave length than the original photon and moves off on a new path



COMPTON EFFECT

Why does the new photon have a longer wave length than the original photon?

It has been slowed down by the collision with the electron - page 4-13

It has less energy than the original, therefore its wave length is longer - page 4-14

From page 4-12

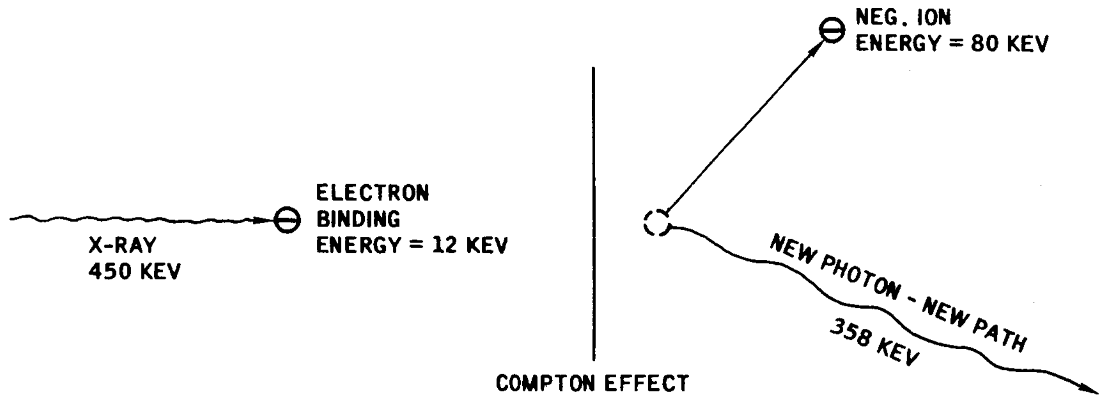
Photons cannot be "slowed down." Remember?

ALL electromagnetic radiation travels at the speed of light.

A photon, regardless of its wave length, travels at the speed of light. When it stops it is no longer a photon. Its either full speed or nothing.

Return to page 4-12 and see if the second choice doesn't match what you know about the relationship of photon wave length to photon energy.

That's right. Some of the energy has been used to eject the electron and to give it some speed. The remaining energy is less than the original, therefore the wave length of the new, scattered photon <u>has</u> to be longer.



COMPTON EFFECT

In the example above, the penetrating photon has an energy of 450 Kev. It removes an electron that has a binding energy of 12 Kev and gives it a boost of 80 Kev. The scattered photon takes a new path different from the original photon and has an energy equal to:

450 KEV - 12 KEV - 80 KEV = 358 KEV

<u>A portion of the original photon energy has been absorbed by the penetrated material thru the process of ionization.</u>

We now have a new, scattered photon of reduced energy. What would be a logical next thought?

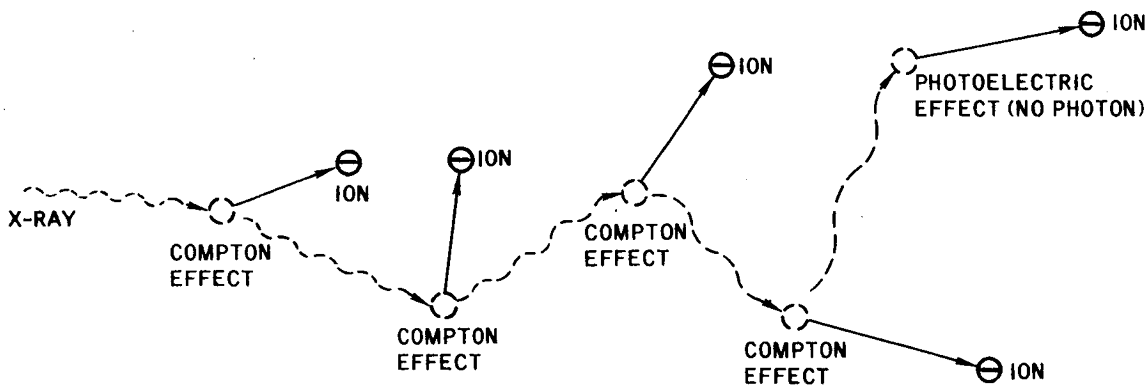
The scattered photon will produce further ionization
by photoelectric effect or by Compton effect - - - - - - - - - - - - - - - - - - - page 4-15

The scattered photon can be ignored because it is
no longer a part of the original X-ray beam - - - - - - - - - - - - - - - - - - - page 4-16

[redacted]

From page 4-14

Correct. The scattered photon will interact with matter and will be absorbed in exactly the same manner as any photon from the original X-ray beam. In fact, it may go through several Compton effect actions before the energy is completely absorbed.



Notice that the collision between the photon and electron is not a "billiard ball" reaction. The angle (change of direction) at which the new photons proceed follow a very definite pattern. Examine the diagram above and see if you can pick it out.

The lower the photon energy, the greater the angle (direction change) at which the new photon proceeds - - - - - - - - - - - - - page 4-17

The first Compton event always results in a small angle (direction change) for the new photon, and subsequent angles get larger and larger - page 4-18

From page 4-14

Sorry. The scattered photon is identical in every respect to the original photon except that it has less energy and a different path. It cannot be ignored.

In fact, these scattered photons create a major problem for the radiographer, as you will learn, and much of his work is involved in trying to control these "wandering" photons.

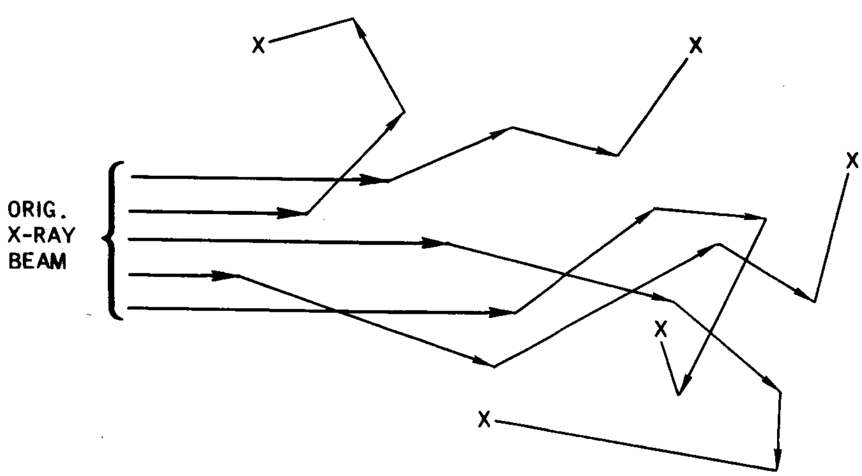
Turn to page 4-15.

You have the right idea. The higher the photon energy, the smaller the change in course for the new photon.

Very high energy photons after Compton effect collision will take a path that is very close to the original path, but it is never the same. In other words, high energy photons scatter very little.

A low energy photon, even if it results from the first Compton effect collision, will take a path that is considerably different from the original. Very low energy photons may even scatter backwards, in an opposite direction.

Here are several photons as they might look when they penetrate a substance and are absorbed in a series of Compton effect interactions and a final photoelectric effect action.



THE LIGHT LINES INDICATE LOWER ENERGY PHOTONS THAT RESULT FROM COMPTON EFFECT. EACH IS ULTIMATELY ABSORBED IN A FINAL PHOTOELECTRIC EFFECT ACTION.

If you were asked to give a name to all of the photons that result from Compton effect, what name would seem appropriate to you?

Secondary radiation - page 4-19

Compton scatter - page 4-20

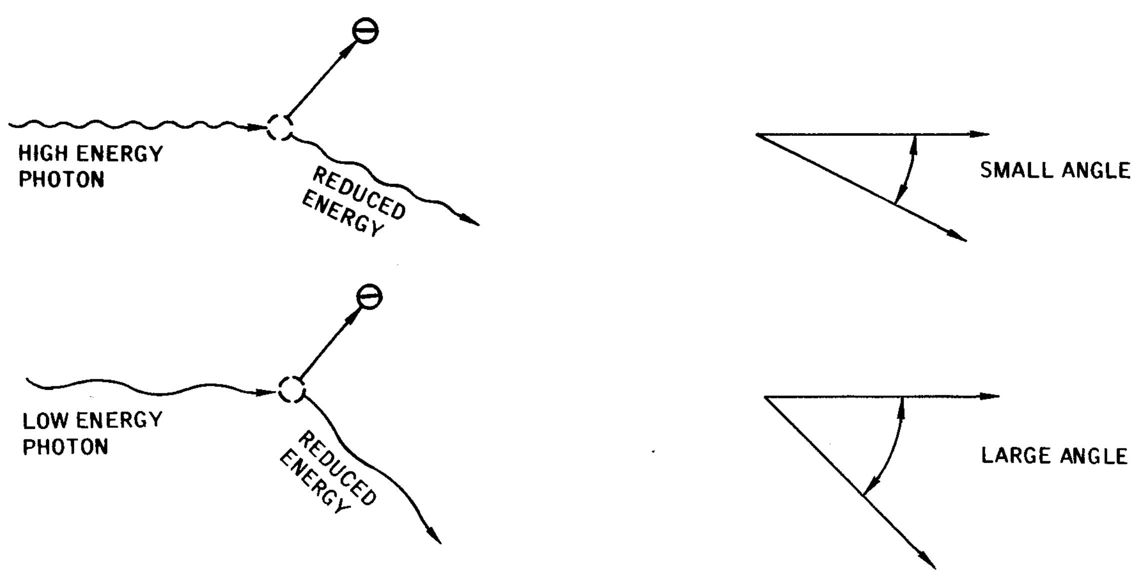
Either or both of the above - page 4-21

From page 4-15

No. Although it might appear that way from the example shown, the first Compton event does not always result in a small angle for the new photon.

There is no difference in the photons before and after a Compton event except for energy and direction. The first photon in the example shown could just as well have come from one or more prior Compton reactions rather than from an original unscattered X-ray beam.

The angles (direction changes) do get larger and larger, but it is the result of lower and lower energies as partial absorption progresses. The size of the angle has nothing to do with whether the reaction is the first, second, third, etc.



Turn to page 4-17

Your choice is a good one although it isn't the one we were after. This radiation that results from Compton effect is logically "secondary" radiation since it isn't part of the primary beam.

However, it is also known as "Compton scatter" since it results from Compton effect and it is certainly well scattered.

The best choice would have been, "Either or both of the above."

Turn to page 4-21

From page 4-17

We agree that "Compton scatter" is an appropriate name for the photons that result from Compton effect.

However wouldn't it also seem appropriate to name it "secondary radiation" since it is not part of the primary X-ray beam?

Your answer isn't wrong, but we were hoping you'd pick "Either or both of the above."

Turn to page 4-21

From page 4-17

Right. Both names, "Secondary radiation" and "Compton scatter" seem appropriate.

COMPTON SCATTER is a more precise name for this particular type of electromagnetic radiation, whereas "secondary radiation" includes other types of radiation that result from action of a primary beam, e.g., the electrons that are ejected during photoelectric effect or Compton effect.

There is another term that is commonly used - scattered radiation. This term has a broad meaning and to the radiographer includes just about any undesirable radiation regardless of type or source.

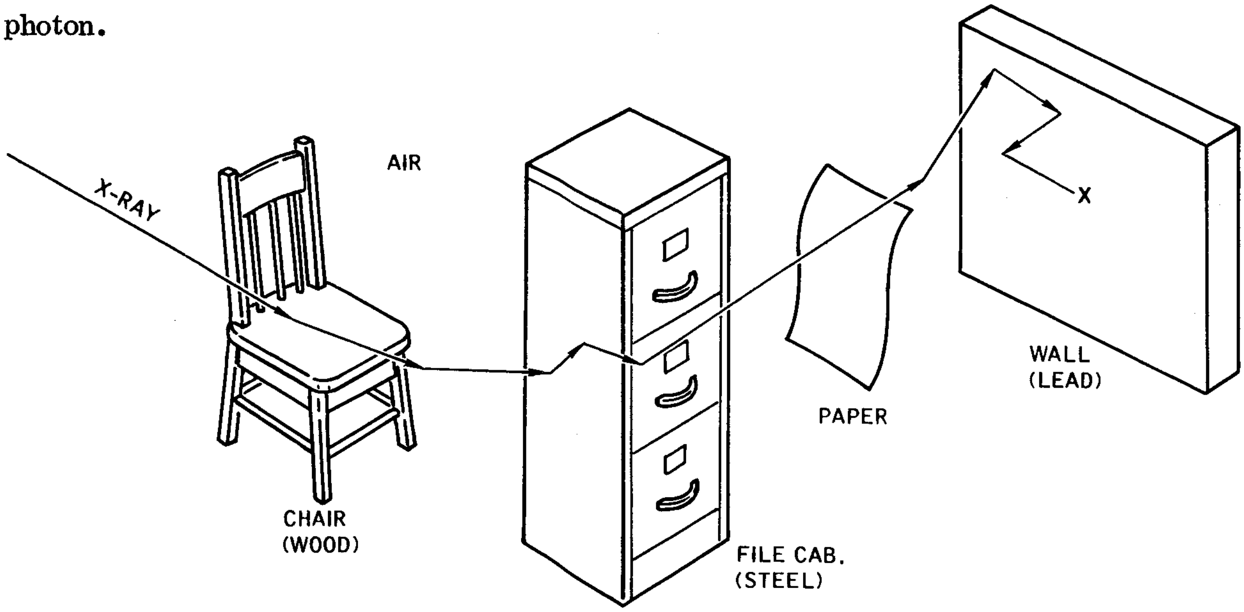
In all of our discussions we'll try to be as specific as possible by labeling the radiation as "primary," that is, part of the original beam, "secondary" if we want to include all types of radiation other than primary, and "Compton scatter" if we are talking about the photons that are scattered as a result of Compton effect.

Turn to page 4-22

From page 4-21

Speaking practically, an X-ray photon would not necessarily expend itself, or be totally absorbed in one material or medium.

Here is a possible cycle of Compton scatter photons originating with one high energy photon.



From this example you can see that photon energy is more likely to be absorbed in the heavier, more dense materials.

Turn to page 4-23

[redacted])

Now we're going to complicate things a little more.

Have you wondered yet about all those high speed electrons that are flying around as the result of photoelectric effect and Compton effect?

Think about it a bit. Every X-ray photon that is absorbed results in at least one and probably many more high speed electrons that have been ejected from atoms. The kinetic energy (energy of motion) of each of these electrons must also be absorbed in some manner.

Electron energies can be absorbed in several ways. One of the more common is thru the creation of more ion pairs. A high speed electron collides with an electron in another atom and knocks it out of orbit. The energy of the first electron is now reduced - it has been shared with the second electron. One or both of these electrons can repeat the process until very little energy remains in any one electron.

These low energy electrons (negative ions) will eventually react with atoms in what are known as "sub-ionization" events. In other words, the atoms are not ionized. The orbital electrons are given a little excess energy, which they eventually give up in the form of very low energy electromagnetic radiation. Do you know what this very low energy electromagnetic radiation might be?

Ultraviolet rays, light, and heat ------------------------- page 4-24
Gamma Rays ------------------------------------- page 4-25

From page 4-23

Good choice. The answer to this one is found in the electromagnetic spectrum that we discussed early in the book. As wave length increases (energy decreases), we move out of the X-ray/gamma ray band into the ultraviolet, visible light, and infra-red (heat) bands.

Although all X and gamma ray absorption eventually winds up in this type of low energy radiation, the quantities are so small in relation to the total mass of material doing the absorbing, that the effects of heat and light would not be noticeable to the radiographer except with extremely sensitive laboratory equipment.

A second common way in which electron energy is absorbed is a process known as "bremsstrahlung." Frightening word, isn't it? It's German and means "braking rays." Bremsstrahlung is a very important phenomenon to radiography. It accounts for the generation of X-rays in an X-ray tube. We'll discuss it briefly here, but you'll get more on the subject in Vol. 3.

Turn to page 4-26

From page 4-23

Now, how did you happen to pick this one? Gamma rays fall in the same category as X-rays on the electromagnetic spectrum.

The energies we are talking about have resulted from the continuous breaking down of the initial X-ray energy to lower and lower levels until now we have many radiations that are below the X-ray/gamma ray band on the electromagnetic spectrum.

Here's the spectrum again.

INCREASING ◄——— ENERGY ———► DECREASING

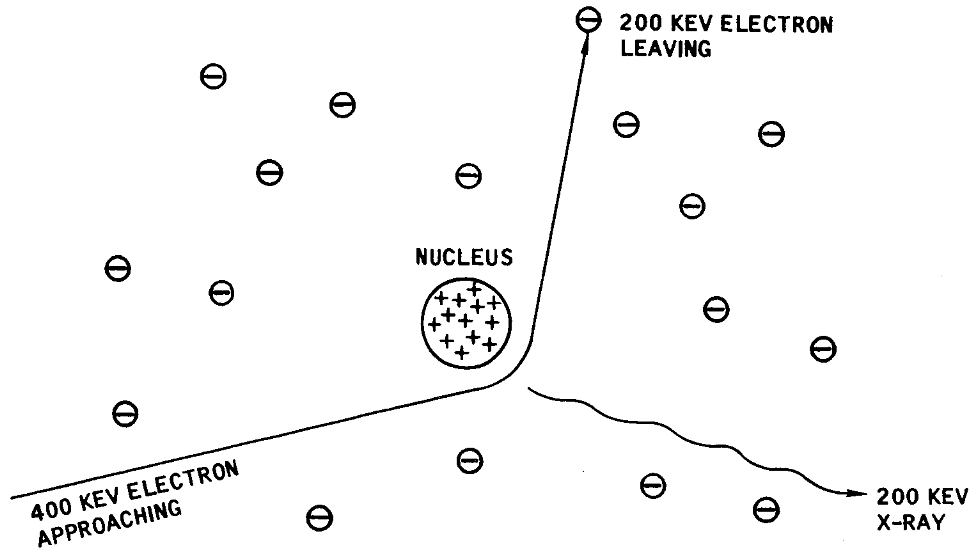
X-RAY AND GAMMA RAYS	ULTRA-VIOLET RAYS	LIGHT	INFRA-RED RAYS (HEAT)	RADAR	RADIO WAVES

Return to page 4-23 and reread the material.

From page 4-24

Bremsstrahlung - braking rays - what does it mean? To "brake" is to slow down or stop.

This is exactly what happens in bremsstrahlung. The high speed electron is slowed down or completely stopped by the positive force field of an atomic nucleus.



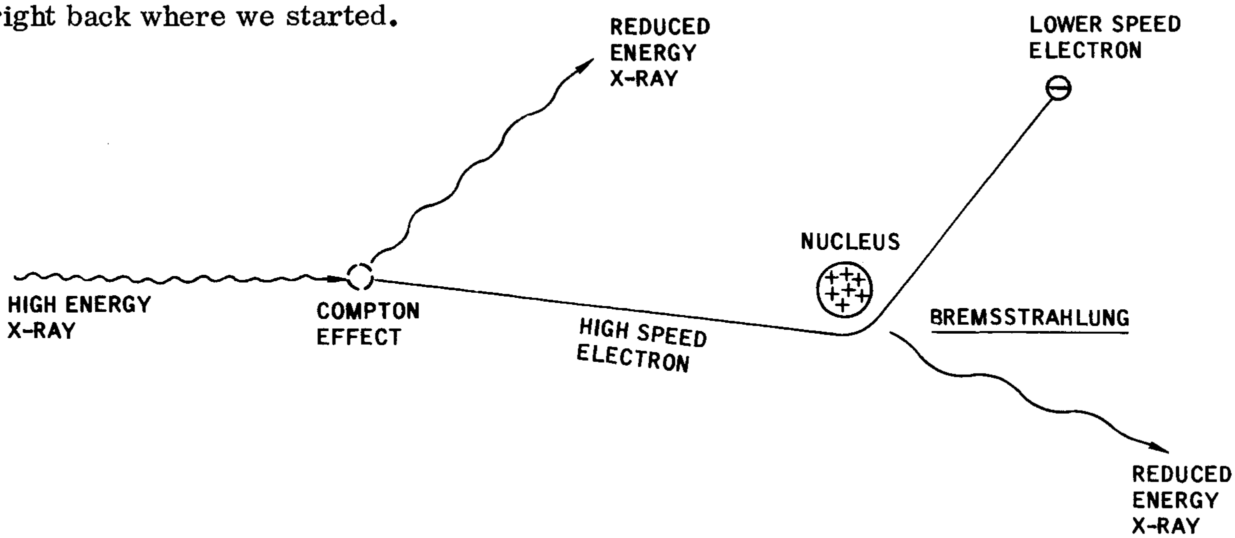
As the fast moving, 400 Kev electron in the above example approaches the nucleus, it interacts with the force field of the nucleus and is slowed down. It leaves the atom at a slower speed, therefore less energy. In the case illustrated, it loses half of its energy and becomes a 200 Kev electron.

The energy that is absorbed in the nuclear force field is now excess to the atom's need so it is immediately radiated as an X-ray of equivalent energy.

If the electron is completely stopped, as may occur when it reacts with very large and heavy nuclei, the radiated X-ray has an energy equal to the total kinetic energy of the electron.

Turn to page 4-27

So, as a result of bremsstrahlung, we have another X-ray. It looks as though we are right back where we started.



The big difference is, of course, that the original X-ray energy has been split into the several lower energies of the secondary radiations.

The new X-rays and the electron will again react in similar fashion to produce more lower energy electrons and lower energy X-rays until finally all we have left is a mass of long wave length (low energy) electromagnetic radiation and molecular excitation (heat) that falls outside the X-ray spectrum.

It's all very complex and a complete analysis defies even the expert.

One thing is certain however -

Compton scatter and secondary radiation in general
is a serious problem for the radiographer - - - - - - - - - - - - - - - - - - page 4-28

this theoretical discussion of scattered radiation
is very interesting but it has no practical
application to radiography - page 4-29

[redacted]

From page 4-27

You're so right. Unless properly controlled, secondary radiation can make it almost impossible to make a satisfactory radiograph. Methods of control and the consequence of not controlling scattered radiation will be covered in volume 4.

In the meantime, let's consider another aspect of the X-ray absorption process - "half value layer."

But first, here's a restatement of a couple of points we covered earlier.

We said that high energy photons had more penetrating ability than low energy photons on an average. All photons, even of the same energies, will not penetrate a given material to the same depth.

We also said that penetration depended also on the density (heaviness) of the material being penetrated. The higher the Z number (more dense), the less the penetration.

Turn to page 4-30

From page 4-27

Here you are in trouble already, and you haven't even finished the first volume. The subject of scattered radiation should be more than just an interesting item to you.

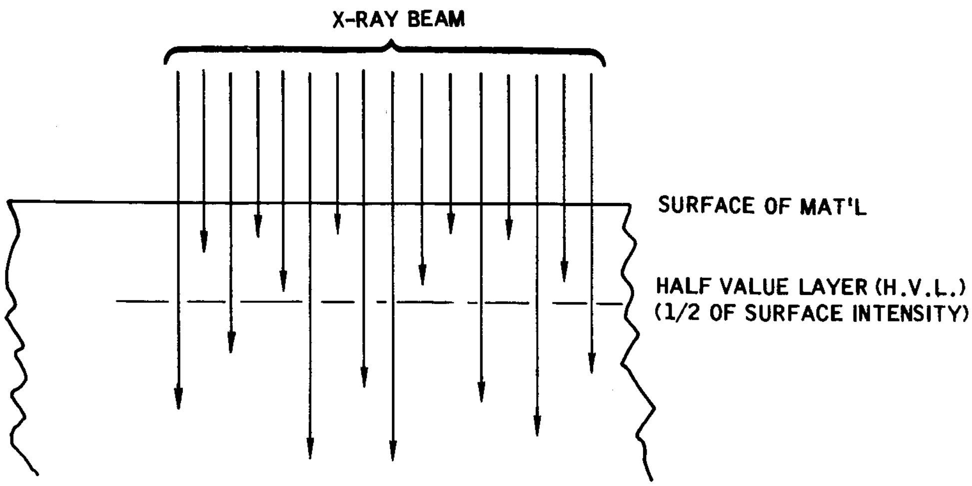
Scattered radiation is a matter of great importance to a radiographer.

Turn to page 4-28

From page 4-28

OK. Let's get back to half value layer.

The absorption of energy from a primary beam of X or gamma rays starts as soon as the beam enters a substance or material.



This absorption process is progressive and as the beam penetrates deeper and deeper, additional energy is absorbed through photoelectric effect and Compton effect.

At some place below the surface, there is a level at which the intensity (number of rays) of the radiation is 1/2 of the intensity at the surface.

This depth is the Half-Value Layer (H.V.L.) for that particular beam in that particular material. What would happen to the half value layer if we used a beam composed of higher energy photons in the same material?

It would remain at the same depth - page 4-31
It would be located deeper in the material - page 4-32

From page 4-30

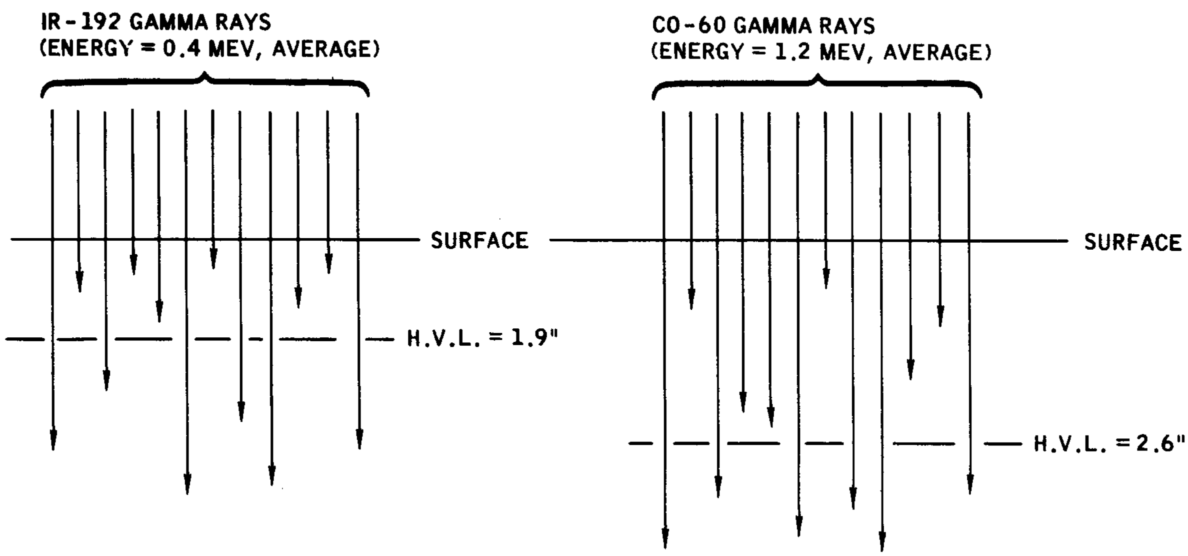
Wrong choice. Remember that high energy photons are more penetrating. Even though the absorption process begins at the surface, <u>the average</u> photon will penetrate to a greater depth.

The point at which the radiation intensity is 1/2 of the surface intensity will be deeper in the material.

Turn to page 4-32

Right. The half value layer would be found deeper in the material due to the greater penetrating power of the high energy photons.

Here's an example using a low density material (aluminum):



The half-value layers (H. V. L.) shown above <u>are always the same for Ir-192 and Co-60 in aluminum</u>. They never change because the photon energies of Ir-192 and Co-60 never change.

Make a mental note of the fact that it doesn't make any difference what the intensity (number of rays) of the original beam is, 1/2 of the rays will always be absorbed at the same depth if the ray energies are the same and the absorbing material is the same.

Now, what would happen to the H. V. L. in the examples shown above if the material were changed from aluminum to lead?

It would be located deeper in the material - page 4-33

It would be located at a shallower depth - page 4-34

From page 4-32

You didn't give this one enough thought before you made your choice.

Lead is obviously a heavier, more dense material than aluminum, therefore X and gamma rays would not penetrate as deeply.

The place at which the intensity is reduced to 1/2 of the surface intensity would not be as deep in the lead as it would in the aluminum.

Turn to page 4-34

[redacted]

Correct. You recognize the fact that the half value layer for heavy, dense materials is less than for light materials.

The H.V.L. for Ir-192 in lead is 0.2 inches, considerably less than the 1.9 inches for aluminum. The H.V.L. for Co-60 is 0.5 inches in lead as opposed to the 2.6 inches in aluminum.

OK? Now give this point a little thought. We have said that in one half value layer the radiation intensity is reduced to 1/2. Now, what fraction of the original radiation intensity will remain at a depth of <u>two</u> half value layers?

1/4 - page 4-35
zero - page 4-36

From page 4-34

Very good! The radiation intensity is reduced by 1/2 for each H.V.L. it passes through. The intensity is reduced to 1/2 by the first H.V.L. and that 1/2 is again reduced by 1/2 by the second H.V.L. $1/2 \times 1/2 = 1/4$

This is similar to the concept of half-life for radioactive isotopes that we discussed earlier in the book.

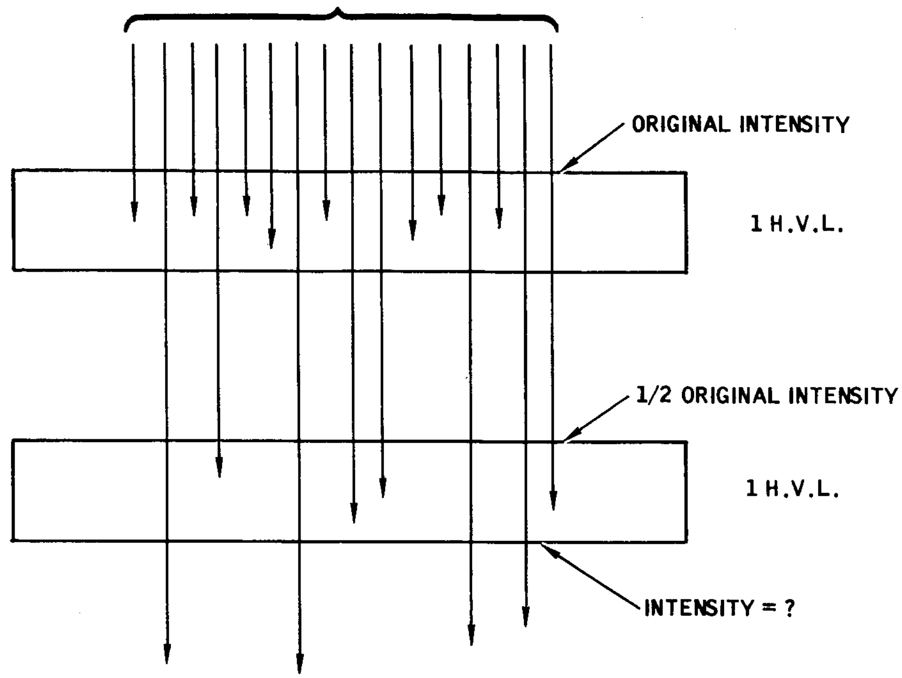
Half value layer is a very important consideration in radiation safety planning. You will have more on the subject in Volume 2.

Turn to page 4-37

From page 4-34

Afraid not.

Look at it this way



All we've done here is to separate the H.V.L.'s to clarify a point.

Turn back to page 4-34 for another choice.

From page 4-35

Here's a brief summary of the points we've discussed in this chapter.

First, X and gamma rays will penetrate light materials more readily than heavy (dense) materials.

Second, X and gamma radiation is absorbed by interacting with matter.

Third, These interactions start with the ionization of atoms in matter.

Fourth, Ionization by photons (X and gamma rays) takes place in two basic ways - photoelectric effect and Compton effect.

Fifth, Photoelectric effect involves lower energy X and gamma rays and results in complete absorption of the photon.

Sixth, Compton effect involves higher energy photons and results in the partial absorption of the photon energy.

Seventh, Scattered electrons resulting from ionization produce additional ionization.

Eighth, Scattered electrons can also result in new low energy X-rays known as bremsstrahlung.

Ninth, "Compton scatter," "secondary radiation," and "scattered radiation" are terms used to describe the results of X or gamma ray interactions.

Tenth, All X and gamma rays are eventually broken up into low energy photons that fall outside the X or gamma ray spectrum.

Eleventh, "Half-value layer" is the depth that X or gamma radiation must penetrate a material to reduce the intensity to 1/2 of the original intensity.

Turn to page 4-38

From page 4-37

1. The penetrating ability of X and gamma rays is dependent upon the ____________ of the rays.

7. negative (-)

8. An atom from which an electron has been removed is a ____________ ____________.

14. 105

15. The new photon that results from Compton effect will ____________ (always) (never) follow the same path as the original photon.

21. ion pairs

22. The constant action and interaction of photons and electrons results in the eventual reduction of the original photon energy to a mass of very low ____________ photons.

1. energy

2. In addition to the energy of the X or gamma rays, penetration is also dependent on the ________________ being penetrated.

8. positive ion

9. When an X-ray or gamma ray photon collides with an orbital electron in an atom, it loses some or all of its ________________ by creating an ion pair.

15. never

16. The angle at which the new photon scatters is a function of the ________________ of the photon.

22. energy

23. Ultraviolet rays, light, and infrared rays are a very low energy form of ________________ ________________ that result from the absorption of X and gamma rays.

2. material (substance, specimen, etc.)

3. Light materials are easier to penetrate than ________________ materials.

9. energy

10. The simplest case in which photon energy is absorbed is the collision wherein all the photon energy is used to overcome the electron's binding energy and to give the electron some energy or speed of its own. This process is known as ____________________ effect.

16. energy

17. In Compton effect, photons with ______________ energy will scatter at greater angles than photons with __________________ energy.

23. electromagnetic radiation

24. Bremsstrahlung is a process in which a high speed electron is slowed or stopped by the electrical field of an atomic nucleus resulting in the emission of an ____________________.

3. dense (heavy)

4. Lead is commonly used as a shielding material against X and gamma rays because it is a very__________________ material.

10. photoelectric

11. If a 100 Kev photon reacts in photoelectric effect with an orbital electron that has a binding force of 10 Kev, the energy of the ejected electron will be __________________Kev.

17. low, high

18. High energy photons can create a series of Compton effect reactions with progressively lower energies until all the photon energy is absorbed in one last_______________effect action.

24. X-ray (photon)

25. The control of Compton scatter or secondary radiation is of_______________ importance to the radiographer.
(no) (great)

4. dense (heavy

5. Photons (X-rays and gamma rays) are absorbed by the materials they penetrate thru the process of i__________ or the creation of __________ pairs.

11. 90

12. In some cases, especially with higher energy photons, there is energy left over when an electron is ejected from an atom. This remaining energy takes the form of a new lower energy photon. This process is known as __________ effect.

18. photoelectric

19. Common terms that are used to describe the scattered photons that result from Compton effect are: __________ scatter; __________ radiation; and scattered __________ .

25. great

26. The thickness of absorbing material that will reduce the radiation intensity by 1/2 is known as the __________ __________ __________.

5. ionization, ion

6. An ion is a charged atom, group of atoms, or atomic particles of either ____________________ or ____________________ sign.

12. Compton

13. The new photon that results from Compton effect is always of lower ____________________ than the original photon.

19. Compton, secondary, radiation

20. The term "secondary radiation" includes all scattered photons and ejected electrons that result from interactions of the ____________________ beam.

26. half value layer

27. Three half value layers will reduce the radiation intensity to ____________________ of the original value.

6. positive (+),
negative (-)

7. An electron that has been removed from an atom is a ______________ ion.

Return to page 4-38, frame 8.

13. energy

14. If a 200 Kev photon ejects a 90 Kev electron that had a binding energy of 5 Kev, the resulting photon will have an energy of ______________ Kev.

Return to page 4-38, frame 15.

20. primary

21. High energy electrons that are ejected from atoms as the result of photo-electric effect and Compton effect, will collide with other orbital electrons and produce more i______________ p______________.

Return to page 4-38, frame 22.

27. 1/8

28. Now turn to the next page and continue with Chapter 5.

CHAPTER 5 — ALPHA, BETA, AND NEUTRON RADIATION.

Most of our discussion this far has been about the electromagnetic wave form of radiation - X-rays and gamma rays. In this chapter you will learn something about "particulate" radiation - radiation composed of particles. We will cover the origins of particulate radiation and some of the characteristics of such radiation. You will also find that because of the characteristics of particulate radiation, it offers relatively little danger to the average radiographer.

Particulate radiation serves no useful function in radiography. However you should have some knowledge of the subject, since many of the sources of gamma radiation are also sources of particulate radiation.

The types of particulate radiation that may be of interest to radiographers are alpha, beta, and neutron radiation. These particles were discussed briefly in Chapter 2, but let's take a closer look at them now.

Particulate radiation differs from electromagnetic radiation in several important ways. Here is a brief comparison:

	electromagnetic	particulate
have mass or weight	no	yes
travel at speed of light	yes	no
affected by magnetic fields	no	(alpha & beta) yes

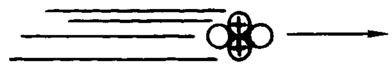
In other ways, particulate and electromagnetic radiation are similar:

ionize matter	yes	yes
is penetrating	yes	yes
detected by human senses	no	no

Turn to page 5-2 and we'll discuss each of the particles in turn.

From page 5-1

Here is an alpha particle. You first saw it in Chapter 2. It is one of the products of radioactive decay in some radioactive isotopes.

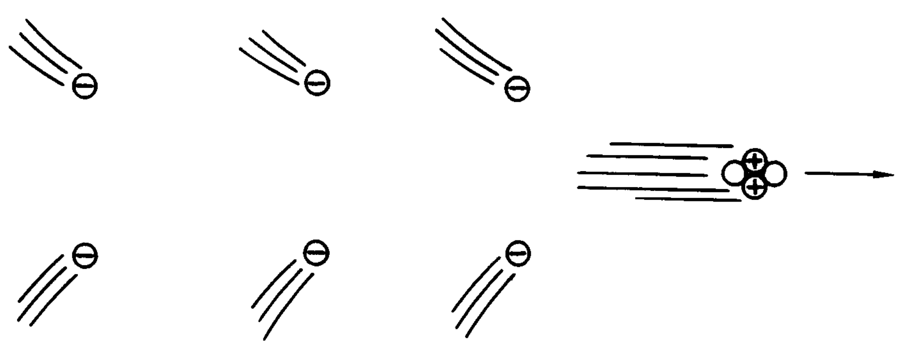


An alpha particle contains 2 neutrons and 2 protons and is actually a helium atom without its electrons.

This is a relatively slow, heavy particle. It weighs over 7000 times as much as a beta particle or an electron.

It also has a plus 2 electrical charge as indicated by the 2 protons.

Because of its slow speed, weight, and charge, it has a considerable effect on materials that it penetrates. It strips electrons from atoms it passes.



What would you say about the ionizing ability of alpha radiation?

Alpha rays are highly ionizing - page 5-3

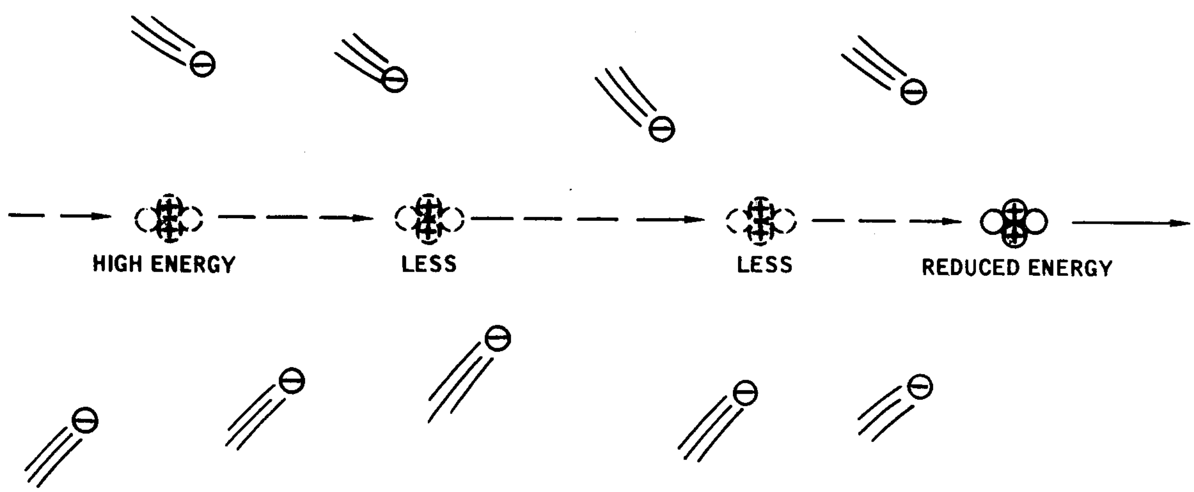
Alpha rays do not ionize. Only X-rays and gamma rays can ionize - - - - - page 5-4

From page 5-2

That's right. Alpha particles are highly ionizing. The heavy alpha particle with its relatively slow speed and its double positive charge has a strong attraction for the light negative electrons. The alpha particle doesn't have to hit an electron directly to dislodge it from an atom. The fact that it passes in the vicinity of the electron is enough to cause the electron to leave the atom.

And when an electron is removed from a complete atom, an <u>ion pair</u> is formed - a negative ion and a positive ion.

Of course it takes energy to remove an electron from an atom. Every time an electron is dislodged, the alpha particle loses some of its kinetic energy or speed.



Considering the fact that alpha particles create large quantities of ions as they penetrate matter, how deeply would you expect an alpha particle to penetrate?

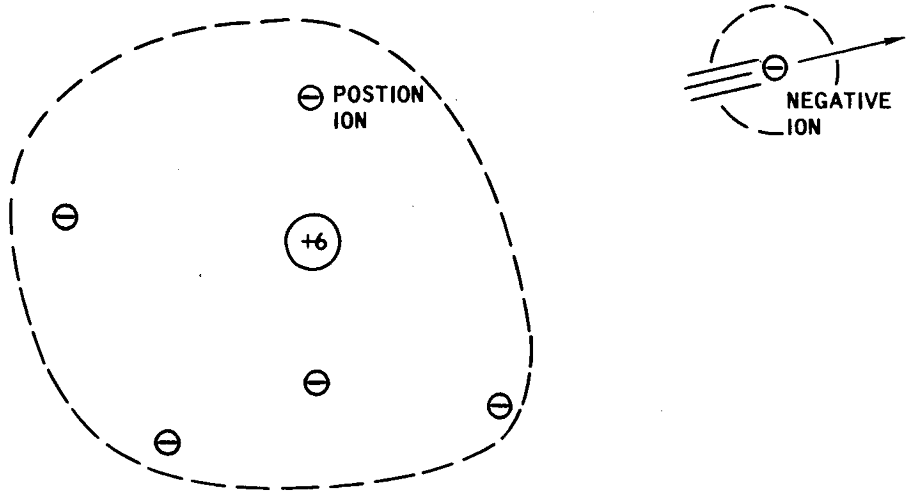
Alpha particles are highly ionizing,
therefore they are highly penetrating - page 5-5

Alpha particles expend their energy fast, therefore
do not penetrate deeply - page 5-6

[redacted]

From page 5-2

Perhaps you've forgotten the definition of an ion. An ion is a charged atom, group of atoms, or atomic particle.



The electrons that are stripped from atoms as the alpha particle passes are negative ions. The atoms from which the electrons are removed become positive ions. Therefore a large number of ion pairs are formed when an alpha particle penetrates any material.

Turn to page 5-3

Sorry. An alpha particle will continue to penetrate only as long as it has some speed or kinetic energy left. The fact that it uses so much energy in removing a large quantity of electrons from atoms means that its speed will drop rapidly.

You might compare it to firing a bullet into water. The drag on the bullet is considerable. Although it starts with a great deal of energy, it loses the energy rapidly and doesn't travel very far into the water.

Turn to page 5-6.

Good. You recognize the fact that because alpha particles react so readily with matter, they will use their energy fast and come to a stop in a short distance.

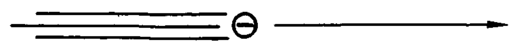
In fact, alpha particles travel such a short distance, even in air, that they are not a real hazard to the radiographer. A single sheet of wrapping paper will completely absorb them.

A word about the actual sources of alpha particles. X-ray equipment does not generate alpha radiation. The only source of alpha particles, so far as you, the radiographer, is concerned is from radium 226. The other radioactive isotopes commonly used in radiography, i.e. cobalt 60, iridium 192, cesium 137, and thulium 170, do not emit alpha particles in their decay process.

Even when using radium, the fact that the radioactive pill is encapsulated (encased in metal) means that all alpha radiation will be absorbed before it is able to pass through the capsule.

Turn to page 5-7 and we'll discuss beta particles.

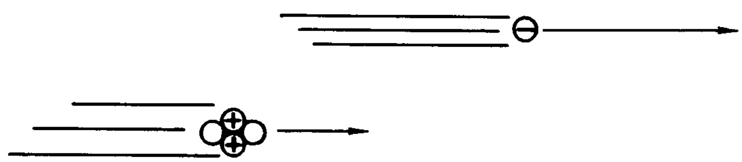
Beta particles are also a product of the radioactive decay of some radioactive isotopes. Here is a representation of a beta particle.



Look familiar? Sure, it's just a high speed electron, however, when it results from radioactive disintegration, (comes from a nucleus), it is called a beta particle.

If you recall, an electron is very light in comparison to a proton or neutron (and therefore to an alpha particle) and it carries an electrical charge of minus 1.

A beta particle will travel at a much greater speed than an alpha particle of the same energy because of its light weight.



We told you that alpha particles were very ionizing because of their slow speed, weight and high positive charge. What would you suspect about the ionizing ability of beta particles?

Beta particles do not ionize materials as readily as alpha particles do - - - - page 5-8

Beta particles are just as ionizing as alpha particles - - - - - - - - - - - - - page 5-9

Right you are. Although beta particles are quite ionizing, they are not nearly as ionizing as alpha particles because of their light weight and single negative charge.

Beta particles will ionize materials by passing very close to, or by direct collision with electrons in the atoms, whereas, alpha particles have merely to pass in the vicinity of atomic electrons to create ions.

One might think from this discussion that beta particles are of even less concern to the radiographer than alpha particles. However, the reverse is true! Take a look at these facts:

> Because of their light weight, beta particles are much faster than alpha particles.
>
> Beta particles do not expend their energy as quickly in ionizing matter.

Considering the above facts, which of the following statements do you think is correct?

Beta particles are more penetrating than alpha particles - - - - - - - - - - page 5-10

Beta particles don't penetrate very deeply because they don't have enough weight and electrical charge to get through - - - - - - - - - - - - - - page 5-11

From page 5-7

You say that beta particles are just as ionizing as alpha particles. Not so.

Look at the reason for the high ionizing ability of the alpha particles. VERY HEAVY, SLOW, and HIGH ELECTRICAL CHARGE.

Now look at a beta particle. VERY LIGHT, FAST, and LOWER ELECTRICAL CHARGE.

Doesn't it seem likely that beta particles would have a different effect on atoms than alpha particles have?

Turn to page 5-8

From page 5-8

Good choice. Beta particles are very fast and do not expend their energy as readily in ionizing a substance, therefore they penetrate to a greater depth. This is one of the things that makes them of greater concern to a radiographer.

Alpha particles, even if they could get through the capsule that encloses the radium, would be stopped by air in an inch or so, or by the upper layer of dead skin on your body, or by a thin surface layer of any other material. The ionization within these short distances would be extremely heavy, but it would be confined to such a limited space that it would not be detrimental to health or the quality of a radiograph.

Beta particles on the other hand do not ionize matter as readily, therefore they penetrate further. This makes them more of a problem because their influence is felt to a greater depth.

Turn to page 5-12

From page 5-8

We must have mislead you. Heavyness is not an aid in penetrating a substance. Take the alpha particle for instance. It is one of the heaviest of the particles we are concerned with, yet it has the least penetration. This is largely due to its low speed. Heavy particles do not travel as fast as light particles of the same energy.

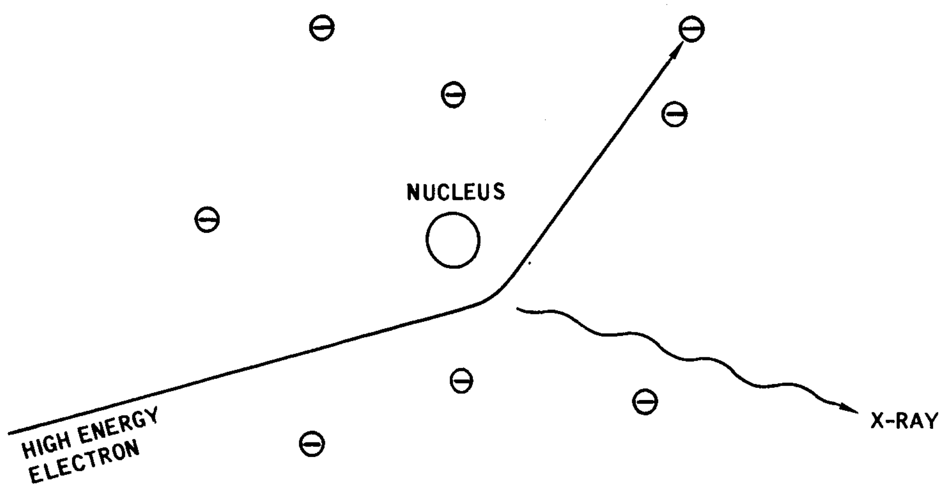
Also, a large electrical charge does not increase penetration. Actually, it limits the amount of penetration because of the interaction of charged particles with atomic electrical charges.

The fact that a beta particle is extremely light (and fast) and has only half the charge of an alpha particle, makes it <u>more</u> <u>penetrating</u> than an alpha particle.

Turn to page 5-10

There is another reason that beta particles are of more concern to a radiographer.

Do you remember this diagram from the last chapter?



This is <u>bremsstrahlung</u> - the generation of an X-ray due to the slowing or braking effect of an atomic nucleus on a high energy (high speed) electron.

Choose a statement.

I remember the diagram and discussion, but what does bremsstrahlung have to do with beta particles? - - - - - - - - - - - - - - - - - page 5-13

I see the connection. Let's go on. - page 5-14

From page 5-12

What does bremsstrahlung have to do with beta particles?

Simply this. Since beta particles are nothing more than high speed (high energy) electrons that originate during radioactive disintegration, there is no reason why they shouldn't react with matter in exactly the same way as any other high speed electron.

When the bremsstrahlung reaction takes place, it doesn't make a bit of difference where the electron originated. If it has enough energy, it is capable of creating an X-ray by being slowed or stopped by an atomic nucleus.

Turn to page 5-14.

From page 5-12

Since the beta particle (high speed electron) can generate bremsstrahlung X-rays by its passage through matter, this means that the radiographer is faced with another source of scattered or secondary radiation.

Being practical, however, the problem is not as great as it might appear, because only a very small percentage of beta particles enter into a bremsstrahlung reaction.

As for the sources of beta particles, all the common radioactive isotopes used in radiography emit beta particles along with the gamma radiation. With one exception, these beta particles have little practical effect on a radiograph.

The exception is thulium 170 in which the beta particles react with the atoms in the source itself before the beta particles even leave the pellet or pill. In other words, the pill of thulium 170 acts as both the source of beta particles and the target which produces the X-rays by slowing or stopping the beta particles.

These bremsstrahlung X-rays must be considered by the radiographer when using thulium 170 as a source of gamma rays.

Turn to page 5-15

From page 5-14

There is one other type of particulate radiation that should be mentioned before we leave the subject. This is neutron radiation. Normally, it would not be discussed in a study of radiography, because none of the sources of X-rays or gamma rays used by radiographers is also a source of neutrons.

However, neutrons have peculiar penetrating qualities that make them useful. They penetrate the very heavy elements with ease and are absorbed readily by some of the lighter elements, particularly hydrogen. This characteristic is just the reverse of X-rays and gamma rays and makes them valuable in some applications where X and gamma radiography won't do the job.

Neutron radiography is a slowly developing field. There are many problems to be solved before it is put to common use. For our purposes, there is little point in getting into any detailed discussion of neutrons or neutron radiography. As long as you stick to X-ray and gamma ray radiography, you should not be concerned with neutron radiation.

However, it seems inevitable that someday neutron radiography will take its place along side X-rays and gamma rays.

Turn to the next page

Here's a brief summary of the points we've discussed in this Chapter.

First, Particulate radiation serves no useful function in radiography.

Second, Particulate radiation differs from electromagnetic radiation in that it has mass or weight, does not travel at the speed of light, is affected by magnetic fields (except neutrons).

Third, Particulate radiation is similar to electromagnetic radiation in that it ionizes matter, is penetrating, cannot be detected by human senses.

Fourth, An alpha particle consists of 2 protons and 2 neutrons. If is relatively slow, heavy, and has a double positive charge.

Fifth, An alpha particle is highly ionizing for short distances.

Sixth, A beta particle is a high speed electron that results from radioactive disintegration. It is fast, light, and has a single negative charge.

Seventh, A beta particle is not as ionizing as an alpha particle, but it is more penetrating.

Eighth, Neutrons have peculiar penetrating qualities that may some day make them useful in radiography.

Now turn to page 5-17 for a review.

From page 5-16

1. Alpha, beta, and neutron radiation are examples of ____________________ radiation.

3. +2

4. Because of their high electrical charge, great weight, and slow speed, alpha particles are highly ____________.

6. beta

7. Beta particles are not as ionizing as alpha particles because they are much ____________ and have a single ____________ electrical charge.

9. neutral (no)

10. None of the common sources of X-rays or gamma rays used by radiographers is also a source of neutron radiation. Therefore ____________ are of no particular concern to a radiographer.

1. particulate

2. A particle that contains two protons and two neutrons is called an ________________ particle.

4. ionizing

5. Because they are so highly ionizing, alpha particles have a very limited ________________.

7. lighter, negative

8. Beta particles will ________________ more deeply than alpha particles, therefore they are of more concern to a radiographer.

10. neutrons

11. Because of the peculiar penetrating qualities of neutrons we will probably hear more and more on the subject of ________________ radiography.

2. alpha

3. An alpha particle has an electrical charge of ____________________.

Return to page 5-17, frame 4.

5. penetration (range)

6. A high speed electron that results from radioactive decay is called a ____________________ particle.

Return to page 5-17, frame 7.

8. penetrate

9. Neutrons are heavy particles with ____________________ charge.

Return to page 5-17, frame 10.

11. neutron

12. Turn to the next page.

You have just completed the first volume of the programmed instruction course on Radiography.

Now you may want to evaluate your knowledge of the material presented in this handbook. A set of self-test questions are included at the end of the book. The answers can be found at the end of the test.

We want to emphasize that the test is for your own evaluation of your knowledge of the subject. If you elect to take the test, be honest with yourself - don't refer to the answers until you have finished. Then you will have a meaningful measure of your knowledge.

Since it is a self-evaluation, there is no grade - no passing score. If you find that you have trouble in some part of the test, it is up to you to review the material until you are satisfied that you know it.

Turn the book around and flip to page T-1 at the end of the book.

RADIOGRAPHIC INSPECTION - VOLUME I - ORIGIN AND NATURE OF RADIATION

Self-Test

1. List the three primary parts of an atom and give their electrical charge (positive, negative, neutral).

   ____________________ ____________________

   ____

2. Atomic number (Z) is based on the number of ____________________ in the atom.

3. An element is identified by the number of ____________________ in its nucleus.

4. Mass Number (A) is based on the combined number of ____________________ and ____________________ in the nucleus of an atom.

5. The neutron may be considered a combination of a ____________________ and an ____________________.

6. Heavy elements have a ____________________ Z number.

7. Isotopes of the same element vary in the number of ____________________ in the nucleus.

8. Isotopes of the same element have the same number of ____________________ in the nucleus.

9. A stable isotope may be made radioactive by exposing it to a high concentration of ____________________ (neutrons) (protons) (alpha particles) in a nuclear reactor.

10. Almost all gamma radiography today is done with artifically activated: (Choose one)

    a) particles
    b) radium
    c) isotopes
    d) X-ray machines

11. Which of the following isotopes are commonly used for radiographic purposes: (Choose two)

    a) Iridium 192
    b) Osmium 188
    c) Cobalt 60
    d) Rubidium 87

12. The process of being radioactive is called: (Choose one)

    a) heating
    b) decay
    c) sex
    d) curie

13. A radioactive isotope can give off two types of radiation: ______________ or ______________ particles, or ______________ rays.

14. An alpha particle is a relatively ______________ (heavy) (light) particle.

15. A beta particle is a high speed ______________.

16. Which of the following types of radiation is commonly used in radiographic testing: (Choose one)

    a) alpha particles
    b) neutrons
    c) gamma rays
    d) beta rays

17. The curie is a measure of the number of ______________ per second of a radioactive source.

18. The activity of a given radioactive source is measured in ______________.

19. A curie of radioactive material will disintegrate at the rate of: (Choose one)

    a) 37 million (3.7×10^7) disintegrations per second

    b) 37 billion (3.7×10^{10}) disintegrations per second

    c) 37 zillion (3.7×10^Z) disintegrations per second

20. The "curie" is a measure of the ______________ (size) (activity) (weight) of a radioactive source.

21. A change in the physical size of a radioactive source will not change the ______________ (activity) (specific activity) but will change the ______________ (activity) (specific activity).

22. The specific activity of radioactive isotopes is measured in: (Choose one)

a) Mev (million electron volts)
b) C/gr (curies per gram)
c) R/hr (Roentgens per hour)
d) c/min (counts per minute)

23. As the frequency of an X or gamma ray increases, the energy ______________ (increases) (decreases) and as the wave length increases, the energy ______________ (increases) (decreases).

24. Greater penetration will be obtained from ________________ (high) (low) energy X or gamma radiation.

25. When the size of a radioactive source is increased, the activity, or number of curies, will increase and the energy of the gamma rays will ________________ (increase) (decrease) (remain the same).

26. Radiation energy is usually expressed in terms of ______________________ (Kev or Mev) (curies per gram) (Roentgens per hour).

27. The amount of X-radiation or gamma radiation is often spoken of as the ________________________ of the radiation.

a) wave-length
b) energy
c) intensity
d) frequency

28. When the number of curies, or activity, of a radioactive source is increased, the __________________________ of the gamma radiation is also increased.

29. The time required for 50 percent of the original number of atoms of a radioactive source to decay is called the ________________ ____________________ .

30. The half-life of Co-60 is 5.3 years. How long would it take for a 10 curie Co-60 source to decay to 2-1/2 curies?

31. The gamma radiation from a Co-60 source has an average energy of 1.2 Mev. What will be the energy of the radiation at the end of one half-life (5.3 years)?

32. A source of Ir-192 has an activity of 20 curies today. What will be its activity at the end of 5 months? (Half-life of Ir 192 = 75 days or 2-1/2 mos).

33. What is the primary difference between X-rays and gamma rays of the same energy? (Choose one)

a) wave length
b) Frequency
c) Velocity
d) Origin

34. The speed at which X and gamma rays travel is: (Choose one)

a) The speed of light
b) The speed of sound
c) It varies with the wave length

35. Check the items that apply to X or gamma radiation:

is a particle ________________
ionizes matter ________________
harmful to humans ________________
electromagnetic ________________
has odor ________________
has mass ________________
speed of light ________________
high frequency ________________
long wave length ________________
is visible ________________

36. A beam of radiation consisting of a single wave length is known as: (Choose one)

a) microscopic radiation
b) monochromatic radiation
c) heterogeneous radiation
d) fluoroscopic radiation

37. Gamma rays from the same isotope always have the same energy. True or False

38. All gamma rays have the same energy. True or False

39. X radiation from an X-ray machine is monochromatic. True or False

40. X-rays have a shorter wave length than radio waves. True or False

41. Short wave length X-rays are commonly described as ________________ (soft) (hard), while long wave length X-rays are described as ________________ (soft) (hard).

42. Soft X-rays have ________________ (more) (less) energy than hard X-rays.

43. What governs the penetrating ability of an X-ray beam? (Choose one)

a) Kilovoltage
b) Time
c) Activity
d) Milliamperage

44. The shorter the wavelength of X or gamma rays ______________________________ ______________________________ . (Choose two)

a) the higher their energy.
b) the faster they travel.
c) the greater their penetrating power.
d) the closer they are to becoming radio waves.

45. It is sometimes more convenient to think of X or gamma radiation as packages of energy, or ______________________________ .

46. The formation of charged particles, some negative and some positive, by the passage of radiation through matter is called ______________________________ .

47. During the process of being absorbed, the two most common ionizing interactions between X or gamma radiation and matter are ______________________________ effect and ______________________________ effect.

48. When a photon knocks an electron out of an atom, the two pieces, one negative (electron) and one positive (atom less electron), are called an ______________ ______________________________ pair.

49. ____________________ (Heavy) (Light) elements make the best absorbers of radiation. That is the reason that ______________________________ is commonly used as a shielding material.

50. "Photoelectric effect" refers to ______________________________ . (Choose one)

a) an electric camera.
b) complete absorption of a photon.
c) the visible electromagnetic spectrum.

51. Scattered radiation has ____________________ (more) (less) energy than the primary radiation.

52. X-rays that take new paths as the result of Compton effect are often referred to as ______________________________ scatter.

53. "Compton Effect" is the mechanism wherein a portion of the X radiation is absorbed and a portion is ______________________________ .

54. ________________ (High) (Low) energy X or gamma rays are not absorbed or scattered as readily as ________________ (high) (low) energy rays.

55. The thickness of absorbing material that will reduce the intensity of an X-ray or gamma ray beam to one half of its original value is known as the ____________ ________________ ____________________ ____________________ of the material.

56. Radioactive sources often emit ________________________________ or ________________________ particles in addition to gamma rays.

57. Are alpha and beta particles as penetrating as gamma rays?

58. What is the electrical charge of an alpha particle? ______ A beta particle? _____

59. Do alpha and beta rays ionize matter?